



# Ground-Water Resources of the Dayton Area, Ohio

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1568

*Prepared in cooperation with  
the Miami Conservancy District  
and the Ohio Department of  
Natural Resources, Division of Water*



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By STANLEY E. NORRIS and ANDREW M. SPIEKER

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**UNITED STATES DEPARTMENT OF THE INTERIOR**

**STEWART L. UDALL, *Secretary***

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## GROUND-WATER RESOURCES OF THE DAYTON AREA, OHIO

By STANLEY E. NORRIS and ANDREW M. SPIEKER

### ABSTRACT

Use of ground water in Dayton and environs, in southwestern Ohio, amounted to 110 mgpd (million gallons per day) in 1938 or about one-fourth of the State's total use of this resource. The Dayton area is highly industrialized and has a rapidly growing population of about 400,000, which is expected to double by the year 2000. Industrial and commercial growth also are expected to continue at a high rate, as is the attendant use of ground water. Concern over the ground-water situation at Dayton and the need for determining whether the sources of ground water are adequate to meet the anticipated future demand led to the investigation on which this report is based.

The area covered by this report includes the city of Dayton, which lies at the confluence of the Mad River, the Stillwater River, and Wolf Creek with the Miami River; the report also includes that part of the Mad River valley extending from the mouth of the river northeastward to Huffman Dam, a distance of about 5½ miles, and that part of the Miami River valley between Dayton and the mouth of Holes Creek about 3½ miles south of the city.

The principal streams in the Dayton area flow in wide valleys, which were cut deep into relatively impermeable bedrock by preglacial streams and partly filled by glacial deposition of sand, gravel, and till. The glacial deposits range in thickness from 150 to 250 feet and consist generally of an upper and a lower sand and gravel aquifer, each about 30-75 feet thick. The upper aquifer is extensively pumped only at the Rohrer's Island well field of the city of Dayton, where water levels are kept high by artificial recharge. Elsewhere, this aquifer is not thick enough to allow sufficient drawdown for the development of high-capacity wells. The aquifers are separated horizontally by a till-rich zone, which occurs as an areally extensive layer of till or as closely associated till lenses and masses. This till-rich zone, which ranges in thickness from 10 to 50 feet and whose top is from 30 to 75 feet below the surface, is poorly permeable and confines water in the lower aquifer under artesian pressure. Recharge to the lower aquifer, in which most wells are screened, occurs largely by vertical leakage through the till-rich zone. The availability of ground water is not presently limited by the rate of leakage through the till-rich zone, as the difference between the piezometric or pressure-indicating surface of the lower aquifer and the water table in the upper aquifer is nowhere greater than about 20 feet. The till-rich zone is locally absent. Where it is absent, the two aquifers are hydraulically connected.

Wells in the Dayton area typically range in depth from 60 to 175 feet and commonly yield 250-2,500 gallons per minute. As determined by pumping tests, the coefficient of permeability of the lower aquifer ranges from 1,000 to 2,500 gpd (gallons per day) per sq ft, and its coefficient of transmissibility ranges from 40,000 to an estimated 250,000 gpd per ft. Where the till-rich zone is absent, the transmissibility may be as high as 500,000 gpd per ft. From pumping-test data, the leakage coefficient of the till zone at the municipal well field on Rohrer Island, in the Mad River valley, was computed as 0.001-0.012 gpd per cu ft and the coefficient of vertical permeability of the till of this zone as 0.02-0.13 gpd per sq ft.

Ground-water recharge in the Dayton area occurs chiefly because pumping induces infiltration of streamflow through the streambed into the upper aquifer. Thus, the availability of ground water depends not only on the physical properties of the aquifers but also on the character of the surface-water flow and the rate at which water can percolate through streambeds under various conditions. Discharge measurements made at several points along the Mad and Miami Rivers on October 4, 1939, at a time of very low flow, showed that the rate of infiltration through the streambeds averaged about 1.7 mgd per acre in artificially ponded areas on Rohrer Island and about 0.07 mgd per acre in the reach of the Miami River extending south from the Main Street Bridge in downtown Dayton to the city limits. The infiltration rate in this part of the Miami River channel was probably at a minimum when the discharge measurements were made. It is estimated to be much higher—averaging about 0.75 mgd per acre—when the discharge at the Main Street gauge is equal to or greater than about 2,000 cfs (cubic feet per second). Flows of this magnitude occur about 20 percent of the time, during which ground-water levels consistently rise in this area.

Ground water is extensively withdrawn in three general areas. One of these areas is in the Mad River valley about 5 miles northeast of the center of town, in the vicinity of Rohrer Island. The other two areas are both in the Miami River valley; one includes most of the central and southern parts of Dayton, and the other is about 2 miles south of Dayton and includes the plants of the Frigidaire Division of General Motors Corp. and the well fields of the Montgomery County Sanitary Department.

Pumpage at the municipal well field on Rohrer Island averages nearly 35 mgd, mostly from the upper aquifer. The supply is maintained artificially by diverting river flow into specially constructed infiltration ditches and lagoons on Rohrer Island. These artificially flooded areas are drained periodically and dredged to remove the accumulated silt and silt so as to maintain a high rate of infiltration into the underlying aquifer. The Rohrer Island area has reached the practical limit of large-scale development, and the city is presently drilling new wells and developing another ground-water supply in the Miami River valley north of Dayton.

Pumpage by industrial and commercial establishments in the central and southern parts of Dayton averages about 40 mgd. Ground-water levels in three observation wells in these areas—at the Fourth Street Station of the Dayton Power & Light Co. (Mt-2), near the Stewart Street Bridge opposite the National Cash Register Co. (Mt-3), and at the Municipal Building near the center of town (Mt-5)—have been in fairly steady decline since the beginning of record. Some wells in this area have gone dry or have been deepened, and pumpage has been reduced locally because of low water levels. Recharge conditions are poor in the central and southern parts of Dayton, largely owing to the siltation of the riverbed and formation of a "channel seal," which retards the rate of stream

infiltration. Water-supply development in the area as a whole is near its practical limit unless the rate of recharge can be increased.

Pumpage for industrial and public supply averages about 25 mgd in the third major area of concentrated pumpage, which centers at a point about 2 miles south of Dayton. Ground-water levels have not been lowered excessively in this area and additional large supplies can be developed. Favorable recharge conditions result from a relatively high rate of stream infiltration and, to a lesser extent, from the presence of permeable kame deposits, which form a group of high hills along the east side of the valley and contribute much ground-water runoff to the valley-fill deposits.

Ground water in the Dayton area, which is in a limestone terrane, is high in calcium and magnesium; the range of hardness as  $\text{CaCO}_3$  of 44 samples analyzed is 203-516 ppm (parts per million). The iron content, 0-3.5 ppm in the samples analyzed, is troublesome. The iron problem is intensified by the presence of iron-precipitating "bacteria" in many wells. Chlorine treatment usually is required for the control of such organisms.

The demand for ground water in the Dayton area is estimated to rise from the 1938 total of 110 mgd to at least 140 mgd by 1975 and to at least 200 mgd by the year 2000. This last quantity is more than can be developed in the area under natural conditions, and an increasing incidence of local water shortages is forecast unless a comprehensive plan is evolved for conserving water and increasing the rate of infiltration to the aquifers.

## INTRODUCTION

### PURPOSE AND SCOPE OF THE INVESTIGATION

The availability of ample supplies of water has been vital to the growth and industrial development of the Dayton area. Ground water, because of its purity and low temperature, has been of special value to industry, and comparatively few cities in Ohio are so abundantly endowed with ground-water resources as is Dayton. Nature's providence is reflected in the fact that nearly one-fourth of the total quantity of ground water used in Ohio is pumped from wells in the Dayton area. The Dayton municipal water system is one of the largest in the Nation where the entire supply is taken from wells.

The use of ground water in the Dayton area has grown enormously in recent years. Figures compiled by the U.S. Geological Survey in 1946 and by the Water Conservation Subdistrict of the Miami Conservancy District in 1954 reveal an increase in water use of about 40 percent in the intervening 8-year period. Indications are that the use of ground water for industrial and municipal purposes will continue to expand in future years. Forecasts by the Presidential Advisory Committee on Water indicate a probable doubling of the Nation's current demand for water for industrial use by 1975. The increase in water use at Dayton may be substantially above the national average if recent trends continue.

Although the demand for water will almost certainly increase, the supply is limited. Even prior to the drought of 1953-54, when com-

paratively little attention was being paid to water supply, some observers speculated that the growth of Dayton might be stunted eventually by the difficulty of obtaining water economically. These observers pointed to the fact that local shortages already had developed; some wells have been abandoned, and a few industrial plants appeared to have reached the maximum practical development of the ground-water resources in their respective areas. Fears of a widespread water shortage became more widespread during the ensuing 2-year drought and were intensified as water levels in observation wells dropped to record lows. Public officials and representatives of industry alike became concerned. Various plans to conserve water or to recharge aquifers were proposed; the principal plan called for the construction of control dams and retarding basins in the headwaters of the major tributary streams to provide for increased dry-weather flow in the Miami River. Increased riverflow during drought, it was asserted, would result in more recharge to the ground-water reservoirs. Systematic dredging of the stream channels in areas of heavy pumping also was proposed as a means of increasing the rate of infiltration to the underlying aquifers.

Thus, alarm caused by the drought and concern for the future resulted in the creation, in 1953, of the Water Conservation Subdistrict of the Miami Conservancy District, which was to study the feasibility of constructing control dams. The Subdistrict in 1956 retained a board of consultants to ascertain the benefits or liabilities of the proposal. The consultants, after collecting basic hydrologic data and making several experiments with artificial recharge, reported that increasing the base flow of the Miami River would not appreciably increase ground-water recharge. On the contrary, they found that reduction of the peak flows necessary to store water for augmenting low flows would inhibit recharge, inasmuch as most infiltration occurs during floods. Thus if flood peaks are reduced, so is much of the recharge.

In 1956 the Water Conservation Subdistrict entered into cooperation with the Branch of Ground Water of the U.S. Geological Survey to conduct the investigation forming the basis of this report, whose objective is a comprehensive review of the problems of greater Dayton's ground-water supply, with particular emphasis on future water requirements and how they can best be met. The scope of the report includes a detailed study of the geology and hydrology of the principal aquifers, a history of ground-water pumpage as related to water-level trends, a review of the quality of ground water, and, not least in importance, an estimate of Dayton's future water needs based on a continuation of present growth of population and industry.



No report is "final," inasmuch as ground-water requirements are constantly changing and are difficult to predict. Thus by 1975 the entire problem may have changed, rendering the present interpretation as obsolete as the old Miami and Erie Canal. It is the authors' purpose to present first the facts, and second their interpretation. Whether or not time alters the validity of the interpretation, the facts stand as a base for any future investigations.

#### PREVIOUS INVESTIGATIONS

The glacial-outwash aquifers of the Dayton area have been described in several reports covering various phases of the geology and ground-water resources of western Ohio. Fuller and Clapp (1912) reported on the Dayton area in their reconnaissance of the ground water of southwestern Ohio. Foerste (1915) wrote about the geology of the area and briefly mentioned the ground-water resources. Stout, Ver Steeg, and Lamb (1943) included a chapter on Montgomery County in their report on the geology of water in Ohio.

The most complete investigation of water resources of the Dayton area made prior to the present one was written by Norris, Cross, and Goldthwait (1948); it covers in much detail the geology of the consolidated rocks and of the glacial deposits and provides data on the hydraulic properties of the aquifers, yields of wells, water quality, and streamflow characteristics.

Walton and Scudder (1960) studied the ground-water resources of the valley-train deposits in the Fairborn area, immediately east of the area of this report.

Norris (1959) studied in detail the hydraulics and hydrology of the valley-fill deposits in the vicinity of the Dayton municipal well field on Rohrer's Island, in the Mad River valley. His report, a byproduct of the present investigation, describes the separation of the valley fill into two aquifers by a clay-rich zone and gives the rate at which water leaks through this semiconfining bed to the lower aquifer.

Streamflow characteristics have been determined by a systematic stream-gaging program, maintained for nearly 50 years in the Dayton area by the U.S. Geological Survey, in cooperation with the Miami Conservancy District and Ohio Department of Natural Resources, Division of Water. Flow characteristics have been tabulated and discussed by Cross (in Norris and others, 1948; Cross and Weber, 1950; Cross and Hedges, 1959). Cross (1950, p. 60-62) also gave a summary of the history of surface-water development, which centered around the Miami-Erie Canal system.

The disastrous flood of March 1913 and the formation of the Miami Conservancy District and construction of five flood-control reservoirs in the Dayton area were described by Morgan (1951).

**PERSONNEL AND ACKNOWLEDGMENTS**

This investigation was made under the supervision of the senior author. Cooperating agencies were the Miami Conservancy District, represented by Max L. Mitchell, chief engineer, and the Ohio Department of Natural Resources, Division of Water, represented by C. V. Youngquist, chief. All water analyses were made in the Columbus laboratory of the Branch of Quality of Water, U.S. Geological Survey under the supervision of G. W. Whetstone, district chemist. Data on streamflow were provided by the Branch of Surface Water, U.S. Geological Survey, represented by L. C. Crawford, district engineer.

A seismic-refraction survey to determine depths to bedrock was made in the spring of 1960 by R. M. Hazlewood of the Denver office of Branch of Geophysics, U.S. Geological Survey.

Mr. Robert E. Raeselin of the Miami Conservancy District collected much of the basic data incorporated in this report and periodically assisted the authors in making water-level measurements.

The authors regret that all the industrial and municipal representatives who furnished information for the report and cooperated in other ways cannot be mentioned here. The contributions of several, however, warrant special mention. Mr. John E. Eschliman of the Ralph L. Woolpert Co., Consulting Engineers of Dayton, furnished most of the information concerning the well fields of the Montgomery County Sanitary Department, including results of several pumping tests his firm had made. The firm of Schaefer & Walton, Consulting Ground Water Hydrologists, Columbus, made available all the basic data of a pumping test at the Miami River well field of the city of Dayton.

Messrs. W. T. Eifert, director, and Robert Stout and Charles R. Stout, of the Dayton Water Department, supplied most of the information concerning the Dayton municipal well fields. Messrs. Loyd C. Huffman, sanitary engineer, and Earl Riber and Kenneth Hilton, of the Montgomery County Sanitary Department, were most cooperative in providing information.

Messrs. F. C. Webster, Glenn L. Herbst, and Gerald Doig of the Dayton Power & Light Co., F. K. Weisser and N. E. Siders of the National Cash Register Co, and G. F. Miller, E. B. Oda, and Doyle Mummert of the Frigidaire Division of General Motors Corp. provided information regarding the use of ground water by their respective industries. The authors are grateful to the many well drillers of the Dayton area who made information available. G. M. Baker & Sons, Inc., Messrs. Clay P. Garrison, Elbert Hays, Lewis C. Harman, A. E. Lotts, the Layne-Ohio Co., Messrs. O. O. Pegg, and Donald J. Roe were among those drillers most frequently consulted. Mr. Roe, of Vandalia, Ohio, was especially helpful in providing several gamma-

ray logs of wells he had drilled and in giving information on pumping tests he had made in the Dayton area.

Mr. Wilbur Cotton, formerly executive secretary of the Miami Conservancy District, was instrumental in providing support for the investigation.

Finally, the authors express appreciation to Mr. O. B. Roemelin, vice president of the Dayton Power & Light Co., whose untiring efforts as chairman of the Water Conservation Committee of the Dayton Chamber of Commerce led to the formation of the Water Conservation Subdistrict of the Miami Conservancy District and ultimately to the support for the present cooperative investigation. Mr. Roemelin has been instrumental in fostering and maintaining interest in water conservation in the Dayton area. It is not an overstatement to say that his interest in Dayton's water problem was the largest single factor in making this report possible.

#### METHODS OF INVESTIGATION

During this investigation, records of 458 wells were collected and these wells were located in the field. Comprehensive inventories of ground-water pumpage in the Dayton area were made in 1955 and 1958. Water levels in about 60 observation wells were measured in 1955 and twice annually in 1958, 1959, and 1960; and contour maps were prepared of the piezometric surface of the lower aquifer. The results of seven pumping tests were analyzed, and chemical analyses of 44 water samples were made.

The presence of widespread sheets of till interbedded with the valley-train deposits led to the use of several specialized criteria for their recognition. These criteria are described in detail under the heading "Specialized Investigational Techniques."

#### WELL-NUMBERING SYSTEM

For purposes of well numbering and the inventory of ground-water pumpage, the Dayton area is divided into six districts. (See pl. 5.) Privately owned wells are assigned numbers by district according to the following plan:

District	Well No.
Central.....	1-100
East.....	101-200
North.....	201-300
West.....	301-400
South Park.....	401-500
Moraine.....	501 and up

All privately owned wells inventoried in the preparation of this report are listed in the section "Records of Wells in the Dayton Area."

Public-supply wells retain the numbers originally designated by waterworks officials. Wells of the Dayton Municipal Water Department are designated by the prefix C, wells of the Montgomery County Sanitary Department by the prefix M, and wells of the Oakwood Water Works by the prefix O. Test wells drilled by the Dayton Municipal Water Department are given their original number prefixed by the letter T. All public-supply wells inventoried in the preparation of this report are listed in the section "Records of Wells in the Dayton Area."

Observation wells in Montgomery County whose records are maintained by the Ohio Division of Water in cooperation with the U.S. Geological Survey are designated by the prefix M<sub>o</sub>. These observation wells are not listed in the well-records section but are described in the section "Hydrographs of Observation Wells," beginning on p. 119.

#### EARLY HISTORY OF GROUND-WATER DEVELOPMENT

In 1880 pumpage at the Dayton waterworks amounted to about 1 mgd (million gallons per day), and total use of ground water in the Dayton area, including that from private wells, is estimated to have been no more than double this amount. By 1938, ground-water pumpage for municipal, industrial, and commercial use in the Dayton area had increased to 110 mgd. These pumpage figures, separated in time by no more than a human lifespan, document the growth of Dayton from little more than a country village to a vast complex of factories, stores, homes, airports, and other components of a modern metropolis. Water in abundance and at low cost was essential to this growth, and it is fully as essential to the preservation of today's industrial economy. Dayton's continued growth depends on the continued availability of ever larger quantities of pure, clean water. Truly, modern civilization has an insatiable thirst.

From the beginning of its settlement by a small band of pioneers, who in 1796 disembarked from flatboats at the confluence of what then were considered three navigable rivers, water has been of paramount interest and concern to Dayton's citizens. During the town's early years, attention was directed chiefly to surface-water sources of supply, to the building of milldams and levees, and to the use of the rivers for transportation.

The Miami and Erie Canal in 1829 linked Dayton to the rest of the world, by way of Cincinnati, and inaugurated Dayton's first significant growth. Canal traffic reached its peak about 1850 and then began its rapid decline, which was coincident with the growth of rail transportation.

The first well dug in Dayton was on the Newcom lot at the corner of Main Street and Monument Avenue, according to the Reverend A. W. Drury (1909, p. 526), who stated that:

In the gravels underlying the original site of the city of Dayton and within a few feet of the surface an abundance of cool, wholesome water was readily secured. \* \* \* wells, both public and private, were sunk in all parts of the original plat. Many thought that no other provisions would be necessary. When larger needs began to present themselves, attention was turned to Mad River as a source of supply. The clear, rapid current of this stream, with a fall double that of the Miami, was well calculated to capture the imagination and inspire the first efforts in securing an adequate water supply.

Reverend Drury went on to state that as early as June 2, 1826,

the common council passed a resolution requesting Mr. E. Brabbam and Mr. V. W. Van Cleve to survey and ascertain the practicability of conveying water from some point on the Mad River into the town of Dayton.

Events evidently moved slowly, however, and according to Reverend Drury not until March 1, 1845, was the Dayton Water Co. incorporated and authorized to "dig trenches, lay pipes, and in every way necessary install a complete plant by which should be secured good and wholesome water from Mad River." Despite this mandate there is no record of anything having been done; likewise, several other efforts to provide a waterworks between 1845 and 1869 failed.

By the 1860's, however, it was recognized that many shallow wells were being contaminated by the effluent from cesspools dug in the same sand-and-gravel formation. The need for sewers led to the establishment in 1869 of the first board of health. In 1869 a bond issue for a waterworks was passed by the voters. A committee was then formed to make recommendations for a water system; Conover (1932, p. 527) reported that:

the Committee favored the "Holly system" or direct pressure (no standpipe) system. Council leased ground at Dutoit and Beacon Streets, and in September, 1869, sunk two wells, each 25 feet in diameter. These were unsatisfactory and the council purchased two acres at the corner of Keowee and Ottawa Streets for \$5,000.

Wells were sunk at the new site. Conover reported (1932, p. 527-528) that:

In 1871 a long trench was made in the vicinity of the wells to serve as a storage reservoir, but within a year it was found necessary to make a direct connection with Mad River in order to secure a sufficient supply, an extensive filter of gravel being relied upon to exclude all impurities.

In 1874, a very dry year, the water supply proved insufficient and the water of Mad River was turned into the service pipe without any attempt to filter the same. This condition continued from July 16 to the latter part of September. The gallery filtration system proved to be a failure and large wells afterward sunk failed to meet requirements.

In 1881, wells were driven in the bed of Mad River, which with various additions and improvements have given an abundant supply of pure water down to the present time.

Many of Dayton's earlier citizens recognized the relationship between ground water and the geology. Writing in the 1880's, Steele and others (1889, p. 88) stated:

But not the least of the advantages derived from the sand and gravel that underlies Dayton is the drainage it affords. It almost obviates the necessity of sewerage. . . . Underneath the City, at a depth of a few feet, runs a constant stream of water, removing impurities of all kinds and preventing disease. In the less densely populated parts of the City it acts as an admirable filter, and carries into wells pure and cold water for drinking and culinary purposes. Now that in parts of the City well water is no longer considered wholesome, the City is indebted to this same [sand and gravel] for the wells at the waterworks.

A more complete interpretation of the geology was written by Conover (1932, p. 214), who reported that:

Dayton's advantages and future prospects, as far as these depend upon an adequate water supply, are due to the geological formation of the valleys centering at Dayton. Great channels and extensive areas were grooved out of the solid rock and into these were borne from the north great quantities of drift in the form of clay and gravel and sand . . .

The lower strata consist for the most part of clays impervious to water. In the vicinity of Dayton, the upper level of the clay is from 20 to 100 feet below the surface of the valleys. Above this clay floor are the strata of gravel and sand in which is the great reservoir of water ready to be tapped for the uses of man.

The "clay floor" to which Conover referred is the top of an extensive till deposit which generally separates the sand and gravel deposits into an upper and a lower aquifer. Evidently, Conover was unaware of the existence of the lower aquifer, in which most wells other than some of the municipal wells at Dayton now are screened.

Along with knowledge of the geological aspects of Dayton's ground-water supply, came the usual prognostications of the "inexhaustible" character of this vital resource. Steele (1889, p. 214) wrote: "The supply seems inexhaustible; however, should the growing population in the future require more water, additional wells can be added to the plant . . . the waterworks will (soon) have a capacity of 17 mgd." Another account (Conover, 1932, p. 214) stated: "Probably no city in the country is more highly favored than Dayton with an abundant supply of pure and delicious water. The wells are practically inexhaustible . . ."

In 1929, C. H. Paul, an engineer, stated in a publication of the Dayton Chamber of Commerce that: "Not only is the present supply adequate for some time to come, but undeveloped water resources, easily available, are controlled by the City, and the search for an adequate water supply will never be one of Dayton's problems. For and in-

dustrial city this is an asset whose value can hardly be overestimated."

Paul made this statement when ground-water pumpage in the Dayton area was about 40 mgd, a little more than one-third the 1958 total.

It is unlikely that Paul or anyone else in the 1920's, and certainly no one of a generation before him, could have foreseen the explosive increase in the rate of industrial expansion and in water use that has characterized the Dayton area in the past 20 years. He and his predecessors, therefore, may be excused for their unqualified optimism at a time when very few facts were available as to the amount of water in storage in the aquifers and the rate of natural replenishment.

And so it has been in this country with resource after resource—timber, mineral deposits, fertile soil, and wild game—to cite better known examples; the initial concept is that their supply is "inexhaustible." Only when actual depletion or sharp conflict between users becomes grim reality do the citizens bestir themselves and begin accurately to evaluate and conserve Nature's bounty. We owe it to some of Dayton's leading citizens, notably Mr. O. B. Reemelin, for pointing to the urgent need for an evaluation of our ground-water resources. Only when facts are at hand can this vital resource be intelligently developed, managed, and conserved.

## GEOGRAPHY

### LOCATION AND AREAL EXTENT

This report considers the greater part of the Dayton metropolitan area, which is in the eastern part of Montgomery County. A narrow strip of the report area lies along the west edge of Greene County (fig. 1). Dayton is in the southwestern part of Ohio, about 30 miles northeast of Cincinnati and 65 miles west of Columbus. The report area covers about 175 square miles, is rectangular, and comprises parts of six 7½-minute topographic quadrangles: Bellbrook, Dayton North, Dayton South, Fairborn, Miamisburg, and Trotwood.

### TOPOGRAPHY AND DRAINAGE

The Dayton area is in the Till Plains section of the Central Lowland physiographic province (Fenneman, 1938, p. 499-518). The land surface is flat to gently rolling and is at an altitude of 900-1,100 feet. A mantle of glacial drift overlies the bedrock. The principal streams—the Miami, Mad, and Stillwater Rivers—are entrenched, and their generally flat flood plains range in altitude from 710 to 780 feet. The downtown part of Dayton is on the flood plain of the Miami River at an altitude of about 740 feet. Locally more

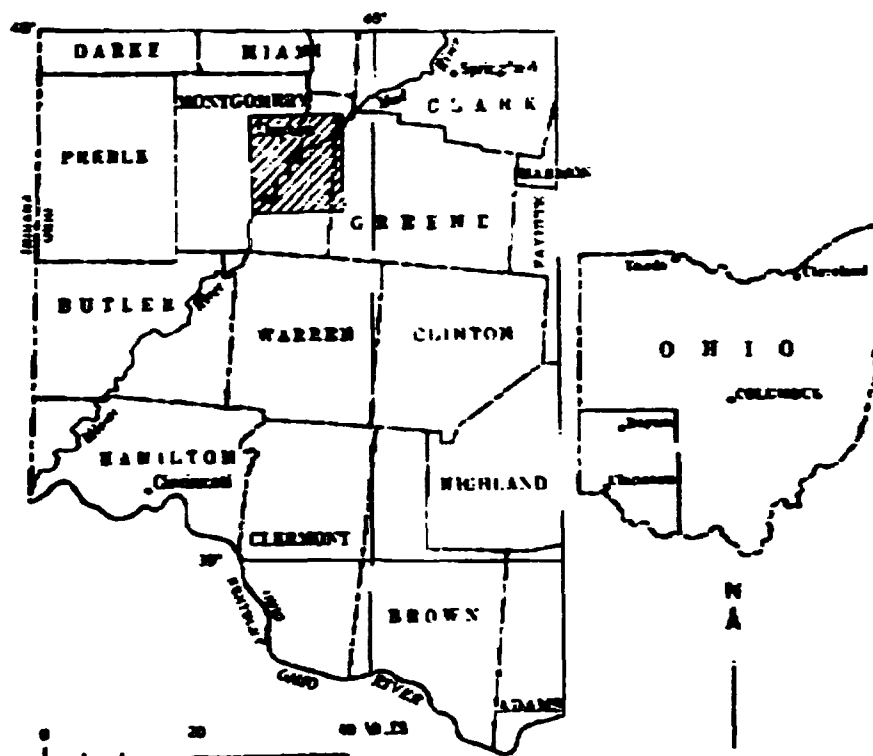


FIGURE 1.—Southwestern Ohio and the Dayton area.

pronounced relief is the result of kames and terminal moraines deposited by the Wisconsin ice sheet.

The area is largely in the drainage basin of the Miami River. Little Beaver Creek, a tributary of the Little Miami River, drains a small part of the city of Kettering, which is in the southeastern part of the area. The principal tributaries of the Miami River in the Dayton area are the Mad River, Stillwater River, Wolf Creek, and Holes Creek.

#### CLIMATE

The Dayton area has a humid temperate climate, a mean annual temperature of 52.7°F, and a mean annual precipitation of 36.75 inches. Normally precipitation is distributed evenly through the year. The average date of the first freezing temperature in the fall is October 21, and that of the last in the spring is April 30. Thus the average length of the growing season is about 6 months. Temperature extremes are rare and of short duration. The record high temperature is 106°F, in July 1901, and the record low temperature



is -28°F, in February 1899. About 1 year in 10 has temperatures above 100°F and 2 years in 8 have temperatures below zero. Snow-fall is moderate; the maximum recorded accumulation is 16.5 inches, in January 1918.

Plate 2 shows the monthly precipitation at Dayton for 1942-60, the period of water-level record in this area. Detailed information on climate is available in a report by Norris, Cross, and Goldthwait (1948, p. 6-9) and in the publications of the U.S. Weather Bureau.

#### POPULATION, INDUSTRY, AND TRANSPORTATION

The population of the Dayton area is about 392,200, according to the 1960 census. This figure is approximate because the area includes fringes of townships bordering those here listed, whose population makes the actual total slightly greater than is shown. Dayton ranks as the 6th largest city in Ohio and the 49th largest in the United States.

Table 1 shows the population trend of the Dayton metropolitan area for the period 1920-60. It can readily be seen that the suburban area has grown relatively faster than the city itself. It is estimated that by the year 2000, the 1960 population will have doubled.

TABLE 1.—Population of the Dayton area, 1920-60

	1920	1930	1940	1950	1960
Montgomery County.....	209,532	273,481	295,480	398,441	527,080
Area of report:					
City of Dayton.....	152,550	200,982	210,718	243,872	262,332
City of Kettering (formerly Van Buren Township).....	7,213	11,271	16,442	22,200	54,462
City of Moline (formerly part of Van Buren Township).....	-----	-----	-----	-----	2,262
City of Oakwood.....	1,473	6,494	7,832	9,691	10,493
Harrison Township.....	7,680	8,985	12,663	27,974	25,998
Mad River Township....	3,283	4,371	4,642	17,860	33,644

The Dayton area is one of the major industrial centers of Ohio. In 1960 there were 738 industrial firms in Montgomery County, about 675 of which were in the area covered by this report. Among their principal products, valued at \$875 million in Montgomery County, are automobile equipment, refrigerators and air-conditioning units, cash registers and related business machines, electrical equipment, paper products, books and printed material, rubber goods, machine tools, and precision instruments.

Industry has a long tradition in the Dayton area. Since 1910 Dayton has been a center of the automotive industry; in recent years the emphasis has been on automotive parts. Much of the industrial growth of the city can be attributed to its proximity to both the

source of raw materials and the markets. The excellent water resources of the area have enabled Dayton to sustain a high level of industrial activity.

The Dayton area is provided with excellent transport facilities. It is on the lines of the Baltimore & Ohio, Erie-Lackawanna, New York Central, and Pennsylvania Railroads and is served also by American, Delta, Lake Central, Trans World, and United Airlines. The area is served by 98 motor freight lines and 9 motor buslines. Several major State and Federal highways link Dayton with all nearby metropolitan centers. Route 75 of the new Federal interstate highway system passes through Dayton, and Interstate Route 70 passes 7 miles north of Dayton.

#### MINERAL RESOURCES

By far the most abundant mineral resources available in the Dayton area are gravel and sand, commercial quantities of which are available almost everywhere in the area shown on plate 1 as "Glacial outwash." Of special interest is the large area of kame moraine where sand and gravel easily can be removed from hillsides. Many large sand and gravel pits are located in all directions from the built-up central district of Dayton.

Limestone is available but is not now quarried in the area of this report, although several limestone quarries are operated in adjacent areas (Norris and others, 1948, p. 12). The limestone of this area probably will never be quarried, as it occurs largely in the densely populated urban area.

#### GEOLOGY

##### CONSOLIDATED ROCKS

The consolidated rocks underlying the valleys and lowlands in the Dayton area consist of shale and thin interbeds of limestone. The limestone layers are hard, coarsely crystalline to dense, and very fossiliferous. They are 1-5 inches thick and may make up 25-50 percent of the entire sequence. The intervening claylike shale is soft, putty-like, and sometimes has distinctive robin's-egg-blue color, which facilitates identification in drill cuttings. The sequence of shale and interbedded limestone was named the Richmond Group after exposures of these rocks near Richmond, Ind. The Richmond Group is of Ordovician age and was deposited as ocean sediments about 430 million years ago.

The Richmond Group is capped on the bedrock divides in the Dayton area by the Bramfield Limestone of Silurian age. The Bramfield Limestone is a light-gray to brown, relatively pure limestone, as much

as 30 feet thick. It is quarried at Fairborn and used in the manufacture of cement. The contact between the Brassfield Limestone and shale of the underlying Richmond Group is well exposed in the railroad cut at the southeast end of Huffman Dam, in the northeastern part of the area.

The consolidated rocks are relatively unimportant as sources of ground water in the Dayton area. The shale and interbedded limestone of the Richmond Group yield barely sufficient water for household wells. Many wells drilled into these rocks are, for all practical purposes, dry. The Brassfield Limestone is a much better aquifer than the Richmond Group and is a generally dependable source of water for farm and home use. The water-yielding properties of the consolidated rocks have been described in detail by Norris, Cross, and Goldthwait (1948).

#### GLACIAL (PLEISTOCENE) DEPOSITS

About 1 million years ago worldwide climatic changes occurred that have resulted in the periodic formation of glacial ice sheets of continental magnitude. Four times, at least, at intervals separated by several tens of thousands of years, these glaciers have spread from centers of accumulation in northern Canada and elsewhere into the northern United States. The four glacial stages are named, from oldest to youngest, the Nebraskan, Kansan, Illinoian, and Wisconsin Stages. Weathered boulders of glacial origin in northeastern Kentucky and diversion of ancient drainage lines in Ohio and other States are evidence that at least one and possibly both of the first two glaciers reached the Dayton area. It is certain that the last two glaciers reached the Dayton area; the Illinoian glacier advanced southward to points a few miles south of Cincinnati, and the Wisconsin glacier stopped a few miles north of Cincinnati. The Illinoian glacier receded from the western Ohio area about 200,000 years ago. Ice of Wisconsin age covered much of Ohio as recently as 14,000 years ago. In a sense the Wisconsin glacier is still in retreat, the remnants of this last great ice sheet being confined now to the Arctic regions.

Each of the four principal glacial stages was influenced by relatively minor climatic fluctuations, and the glaciers alternately advanced and retreated over the area. These oscillations, less widespread than those that characterized the principal glacial advances, are known as substages. Evidence of Illinoian and older substages has not been recognized in Ohio. Wisconsin-age deposits in western Ohio have been related to two substages, corresponding to early and late Wisconsin time. Largely on the basis of radiocarbon-dating

methods, Goldthwait estimated (1938, p. 209) that the first Wisconsin advance reached western Ohio more than 37,500 years ago. The last major advance of the Wisconsin ice commenced between 25,000 and 19,500 years ago; the ice began to recede from its southern terminus, near Cincinnati, about 17,000 years ago, and it disappeared from Ohio about 14,000 years ago (Goldthwait, 1939, p. 198-199, 311, 313). The Wisconsin ice readvanced locally during its final retreat and in many areas deposited till on sand and gravel that had been but recently laid down. This is shown by extensive areas in which till overlies gravel near Dayton, generally on the higher land adjacent to the major valleys both north and south of the city (pl. 1; and Goldthwait, in Norris and others, 1948, p. 34).

The glaciers transported into western Ohio vast quantities of rock and soil, most of it brought from no great distance, but some of it originating as far away as Northern United States and Canada. When the glaciers melted, the soil and rock debris was left on the bedrock, either in the form of till or as sand and gravel, according to the way it was deposited.

#### TILL

Till was deposited directly by the ice as it moved over the area; it is a heterogeneous mixture of clay and stones and lacks assortment or stratification. It covers most of the upland areas (pl. 1) to depths of a few feet and is 80 feet thick or more where it fills depressions in the underlying bedrock surface. Locally, as at the limestone quarries near Fairborn, it is thin or absent.

Till of Wisconsin age weathers to a yellowish-brown to dark, silty clay loam, typical of glacial limestone soils. Below the soil zone downward to the base of the zone of oxidation, which may extend 10-20 feet below the surface, the till is light brown and is fairly easy to dig. Unoxidized till is blue gray and is relatively hard and tough. The well driller commonly reports it as blue clay or hardpan.

From time to time, as the glaciers advanced over or retreated from the Dayton area, tongues of ice lay in the valleys. When these ice tongues melted, the till they contained was deposited as widespread layers or, locally, as blocks and lenses. In some areas these till deposits were removed or cut through by melt water. In most places the till was buried by outwash sand and gravel and remains much as in its original form.

Till, being relatively impermeable, is a major factor in the hydrologic cycle in the Dayton area because it is generally interbedded with the sand and gravel deposits in the large valleys and it slows recharge to the underlying aquifers.

## OUTWASH

When the glaciers melted and the ice fronts retreated, the waters derived from the melting ice poured down the valleys, filling them with vast quantities of sand and gravel, called outwash or valley train. The term "outwash" is appropriate, for the material literally was washed out of the glacier. Most of the outwash deposits in the Dayton area were left by ice of the two Wisconsin substages. The deposits of the earlier glaciers had been largely removed by erosion and transported to the sea by the rivers and creeks that occupied the valleys during the ensuing interglacial stages.

The outwash deposits in the Dayton area range in thickness from about 120 to 250 feet. They are the sole source of the large groundwater supplies that are pumped for municipal and industrial use. The deposits thus constitute, indirectly, a vital natural resource of inestimable worth.

## GEOLOGIC HISTORY

## DEPOSITION AND UPLIFT OF CONSOLIDATED ROCKS

A shallow sea occupied the Dayton area during much of the Paleozoic Era, which began more than 600 million years ago and ended about 230 million years ago. During that time sediments accumulated in the sea and gradually became compacted into the consolidated rocks. Shale of the Richmond Group was once chiefly mud brought to the sea by rivers heading in landmasses to the east and southeast. The limestone layers of the Richmond Group are made up largely of the calcareous remains of organisms that lived in the former sea. The overlying Brassfield Limestone also was derived from the limy remains of these organisms.

During much of the Paleozoic Era the Dayton area emerged above water as part of a low-lying landmass or chain of islands. These emergent lands were along the crest of the Cincinnati arch, whose axis traverses western Ohio along a generally north-south line that passes through Cincinnati and Toledo. According to Stout (1941, p. 13), the Cincinnati arch was formed by subsidence of the rocks along the flanks of a resistant core. This core possibly is formed of crystalline rocks (Lockett, 1947, p. 435). The crest of the Cincinnati arch stood at or near sea level for long intervals of geologic time. The strata thicken on both flanks of the arch and dip off the crest at low angles. In Montgomery County, which is on the crest of the arch, the consolidated rocks dip approximately 5 feet per mile to the northeast, parallel to the axis of the crest (Norris and others, 1948, p. 22).

The final emergence of the western Ohio area took place near the end of the Paleozoic Era. Streams formed on the new land and began their slow work of transporting sediment to the sea. In the millions

of years since the end of the Paleozoic Era erosion has removed many feet of younger sediments, to expose those that presently compose the bedrock. As erosion went on, the area more than once was reduced to a relatively flat surface, known as a peneplain. Typically, after a peneplain, or an incipient peneplain, had been developed, the area would be uplifted slightly, or for some other reason the base level of the streams would change, and dissection of the surface would begin anew. The bedrock surface in the Dayton area ranges in altitude generally between 900 and 1,000 feet. This surface represents a well-developed peneplain, the Lexington, which can be traced over much of western Ohio, eastern Indiana, and Kentucky. The Lexington peneplain was uplifted in several stages, according to Fenneman (1938, p. 441, 443). The last rise occurred in late Tertiary time, perhaps 10 or 15 million years ago, and resulted in the deep trenching of valleys.

In Logan County, about 50 miles north of Dayton, is a small area of higher terrain which reaches a general altitude of more than 1,900 feet and contains the highest point (1,550 ft) in Ohio. This higher area, known to geologists as the Bellefontaine outlier, is an erosional remnant of the Harrisburg peneplain, a well-developed surface in southeastern Ohio and adjacent States. Rocks of the Bellefontaine outlier include limestone and shale of Silurian and Devonian ages, which are younger than the bedrock in the Dayton area. These younger rocks are areally extensive in central and eastern Ohio, as they formerly were in much of western Ohio.

#### PREGLACIAL (TEAYS STAGE) DRAINAGE

The main streams draining the Central Lowland province flowed generally northwestward from at least the beginning of the Lexington cycle until the drainage was disrupted by glaciers early in the Pleistocene Epoch. The principal preglacial (actually late Tertiary) stream is called the Teays River. The Teays River, which compared in size with the present Ohio River, flowed from the Piedmont Plateau of Virginia and the Carolinas across West Virginia, Ohio, Indiana, and Illinois to the Mississippi embayment. It entered Ohio at a point near Portsmouth, flowed north to the vicinity of Chillicothe, and thence generally northwest past London, Springfield, Sidney, and St. Marys to the Indiana line (Stout and others, 1943, p. 32). The course of the Teays River lay about 30 miles northeast of Dayton at its nearest point (fig. 2).

South of Chillicothe, in the unglaciated part of Ohio, the Teays River valley is  $1\frac{1}{2}$ -2 miles wide and lies about 200-250 feet below the hills on either side. The valley is choked with 50 feet or more of

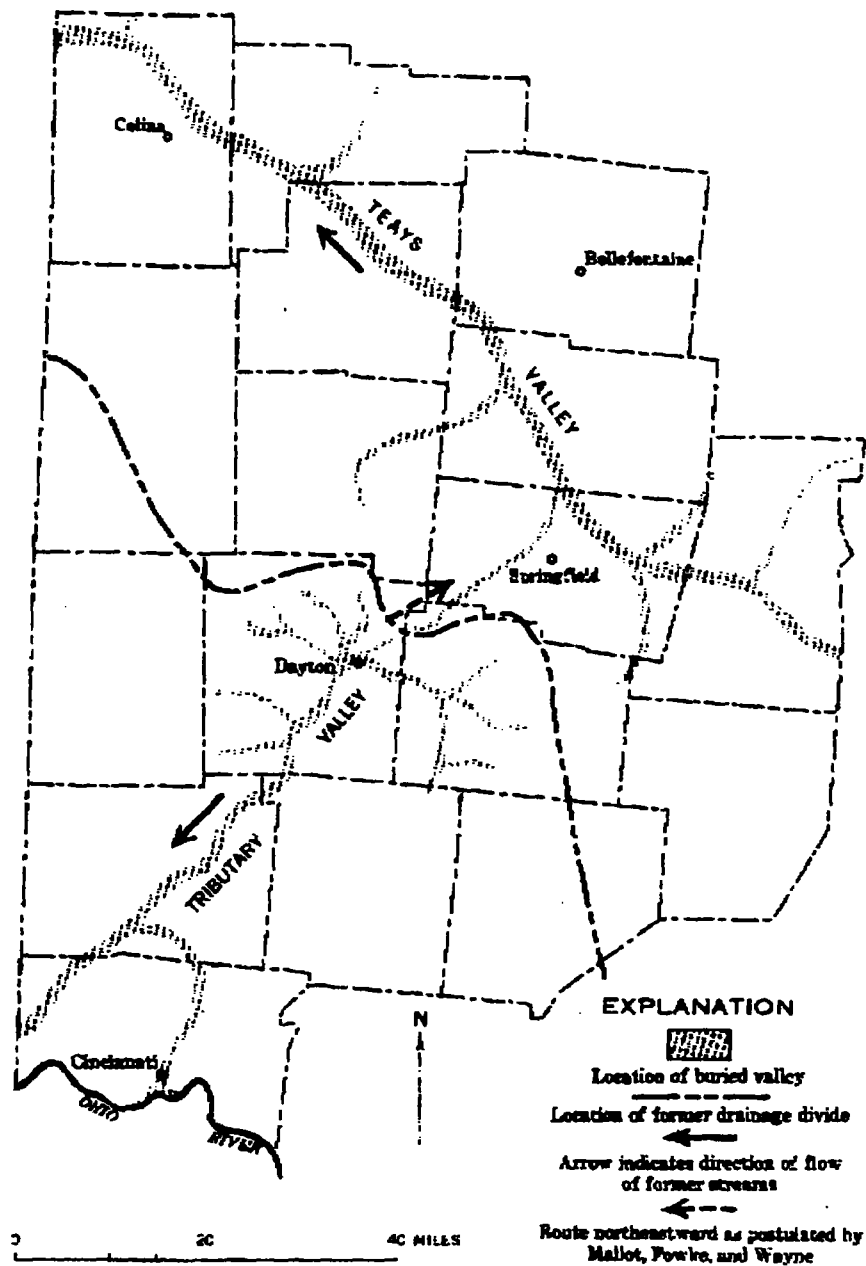


FIGURE 2.—Approximate location of Teays Stage valleys in western Ohio (modified from Stout and others, 1948).

lacustrine clay and alluvium, which forms a relatively flat floor upon which the modern streams flow. The courses and gradients of the modern streams bear little or no relation to those of the former Teays River.

The gradient of the Teays Valley between Wheelersburg, on the Ohio River, and a point near Lake St. Marys, in Mercer County, is about 10 inches per mile. The altitude of the valley floor is given by Stout, Ver Steeg, and Lamb (1943, p. 53) as 660 feet at Huntington, W. Va.; 650 feet near Wheelersburg, Scioto County; 630 feet at Omega, Pike County; and 590 feet at Chillicothe, in Ross County. North of Chillicothe the Teays River valley is buried by glacial drift, and its course is known only from well records and the results of geophysical investigations. The altitude of the buried Teays River valley, determined by test drilling, is 568 feet in the south-central part of Madison County; 556 feet near London, in Madison County; 548 feet near Springfield, in Clark County; and 538 feet in the southern part of Champaign County, west of Urbana (Norris and Spicer, 1958, p. 216). The altitude of the buried Teays River valley near the Indiana line is given by Stout, Ver Steeg, and Lamb (1943, p. 53) as 460 feet.

At various points along its course in Ohio the Teays River was joined by major tributaries (fig. 2), which, like the Teays River itself, carved broad deep valleys. The tributary valleys join the Teays River valley at accordant levels, and the entire system is well graded to the same regional base level. This stage in the peneplanation of a region is known as the strath stage and here marks the beginning of another peneplain at a lower level than the Lexington surface. The level represented by the bedrock floor of the Teays River valley and its major tributaries is called the Parker strath (Fenneman, 1938, p. 301). In southern Ohio the Teays River valley was abandoned as a major drainageway when the Parker erosional cycle was disrupted at the beginning of the Pleistocene Epoch. In other areas the Teays Stage valleys were used by streams of later drainage systems, some of which flowed in opposite directions to the Teays Stage streams. Where this occurred, the younger streams commonly cut below the levels established in Teays time, leaving remnants of the Parker strath as terraces along the valley walls.

The major valleys in the Dayton area were established, at least in part, by Teays River tributaries. Geologists are in general agreement on this point; however, opinions are sharply divided concerning the direction of flow of these tributaries and the level to which they cut their valleys during the Teays cycle. According to Stout, Ver Steeg, and Lamb (1943, p. 70), the Dayton area was a headwaters area in



Teays time and was drained by a south-flowing tributary, which they called the Hamilton River. They wrote (1943, p. 70) that the Hamilton River "gathered its headwaters south of the col [constriction in a valley; this one is at the site of a former divide from which streams flowed in opposite directions] at West Milton on the present Stillwater River, near Tadmor on the present Miami River, and above Harshman on the present Mad River. The stream thus formed by the convergence of tributaries at Dayton flowed southwestward past Miamisburg \* \* \* Middletown \* \* \* and Hamilton." The Hamilton River, according to these geologists, joined with larger tributaries that turned westward near Cincinnati and entered the Teays River somewhere in Indiana.

The altitude of the Teays tributary valley at Dayton was estimated by Stout, Ver Steeg, and Lamb to have been about 714 feet. This is approximately 175 feet higher than the Teays River valley in southern Champaign County; however, a wide difference in altitude between these valleys would be expected, if Dayton were part of a headwaters area as the aforementioned geologists believed. Norris (1948, p. 148), concurring with this interpretation, stated that in Montgomery County "remnants of the Teays valley floor occur as terraces along the sides of some of the more recent valleys at elevations ranging from 750 to 770 feet for former tributaries in the northern part of the county, to elevations as low as 650 feet along the main stream in the southern part of the county."

Stout, Ver Steeg, and Lamb's hypothesis of a south-flowing Teays tributary in the Dayton area was challenged by W. J. Wayne, who studied the buried Teays drainage system in Indiana. Wayne (1953, p. 575-585) favored the view advanced by Malott (1922, p. 136-138) and Fowke (1925, p. 87) that, prior to the formation of the Ohio River, the Kentucky River flowed northeastward through "the old Miami Valley" to a junction with the Teays River in northwestern Ohio. If this is true, the principal Teays tributary in Dayton flowed at a level only slightly above that of the master stream, which crossed the State only a few miles northeast of Dayton. The altitude of the valley of a hypothetical north-flowing Teays tributary would be about 570 feet in downtown Dayton. This figure was obtained by assuming a gradient of about 1 foot per mile for the tributary stream and the likelihood that such a stream would have joined the Teays River some 30 miles downstream in Champaign County, where the altitude of the Teays River valley floor is 538 feet (Norris and Spicer, 1958, p. 218).

Neither the hypothesis of Stout, Ver Steeg, and Lamb, nor that advanced by Wayne, Malott, and Fowke can be affirmed on the basis of evidence obtained in the area of this report. The generalized

character of the bedrock contours on the geologic map (pl. 1), which are based on records of wells, indicates that insufficient data are available with which to form an interpretation. The map, as it is drawn, does show a wide bench or terrace in the bedrock between altitudes of about 550 and 600 feet, overlying on both sides of a much narrower and deeper valley. This terrace level may represent the floor of an early valley, possibly of Teays age. The narrower and deeper channel represents the valley of a Deep Stage stream.

The direction of flow in the Dayton area of the Teays Stage streams (south, as Stout, Ver Steeg, and Lamb stated, or north as Wayne believed) is a matter of speculation for the time being. Stout, Ver Steeg, and Lamb's concept has been criticized on the basis that the divides supposedly located at West Milton, Tadmor, and near Harshman (at the site of Huffman Dam) are only about 25 miles from the Teays River valley, and two major drainage systems would not have coexisted so close together in similar geologic terrane at such widely divergent levels. Moreover, these divides, if there were such, must have been relatively narrow, perhaps much less than a mile wide, as judged from inspection of a topographic map. It would be indeed fortuitous, say the critics, if during the long Teays interval the tributaries of two major streams, the Teays River and the Hamilton River, rose within a few thousand feet of each other without one or the other being captured by stream piracy. And, finally, the critics point out, many of the bedrock valleys that relate to the so-called Hamilton River appear to have contained north-flowing streams, rather than south-flowing streams, as postulated by Stout, Ver Steeg, and Lamb.

In criticism of Wayne's hypothesis, on the other hand, insofar as the Dayton area is concerned, the cols at Tadmor and West Milton are much less than half a mile wide, which clearly seems too narrow to accommodate a major Teays tributary that Wayne said carried the drainage of the entire Kentucky River basin. The third col, at the site of Huffman Dam, is about 3,000 feet wide and could have served as outlet for the waters of a major stream. However, a way has not been found by which such a stream could have reached the Teays River valley in Champaign County. The route northeastward by way of the Mad River valley is blocked by a col, which is only about one-fourth of a mile wide near Springfield (Norris and others, 1962, pl. 1). Control on bedrock mapping in western Clark County is so complete as to virtually rule out passage of a major north-flowing Teays tributary, except possibly between Madway and New Carlisle. To enter the Teays River valley, such a stream would have had to turn west at New Carlisle and follow a circuitous route northward through

eastern Miami County and thence eastward to the Teays River valley in the vicinity of St. Paris in western Champaign County. Few wells have been drilled to bedrock in eastern Miami County, and the possibility that a buried valley having the course just described exists cannot be ruled out. What amounts to "negative" evidence, however, hardly seems a sound basis for the support of a far-reaching concept such as Wayne's.

Elements of both concepts may be correct. The Hamilton River may have come into being at the time of uplift of the Lexington peneplain and may have followed the course described by Stout, Ver Steeg, and Lamb. Eventual reduction of the col at Huffman Dam and headward erosion of a Teays tributary originating in Champaign County may have reversed the upper Hamilton River, which then followed a course northward as suggested by Wayne. Whatever the truth, and evidence may become available someday that will settle the issue, after several million or several tens of million years, the Teays drainage system was completely disrupted and obliterated by the great ice sheets of the Pleistocene Epoch.

#### PLEISTOCENE GLACIATION

##### PRE-ILLINOIAN GLACIER

The Teays drainage system was disrupted and a new stream system was started when an early glacier, possibly the first of the Pleistocene Epoch, advanced southward into the Central Lowland province. This early glacier dammed the Teays River by filling the valley with glacial drift, thus producing widespread lakes in the valleys of the Teays River and its principal tributaries. These lakes were in existence for a long time, as indicated by thick and extensive deposits of lake clay and silt which accumulated in the valleys. The lake deposits extend well to the north of the glacial boundary, indicating that the glacier that dammed the Teays River did not advance as far south as did the ice of later stages. The damming may have occurred in Ohio (Stout and others, 1943, p. 78) or in the area southwest of Ft. Wayne, Ind. (Norris and Spicer, 1958, p. 219-225).

##### MINFORD SILT

Stout and Schaaf (1931) named the aforementioned lake deposits the Minford Silt, from exposures in southern Ohio. In southern Ohio the formation attains a maximum thickness of more than 80 feet and is found at altitudes as high as 860 feet. In and near Madison County, in west-central Ohio, where the Teays River valley is completely buried by glacial drift, the Minford Silt at the sites of 12 scattered test holes ranges in thickness from 18 to 264 feet (Nor-

lowest known point on the bedrock is beneath the intersection of First and Findlay Streets, where a well drilled for gas or oil in 1887 reached bedrock at a depth of 247 feet, or at an altitude of approximately 500 feet. Only fragmentary data are available relative to the altitude of the floor of the buried Deep Stage valley south of Dayton. At Venice (Ross Post Office), 7 miles south of Hamilton, the altitude of the buried valley floor is 364 feet. If the altitude at Venice and the altitude of 500 feet determined at First and Findlay Streets in Dayton are the minimum for their respective locations, the Deep Stage valley between these points, 45 miles apart, has a gradient of about 3 feet per mile. This is about the same as the gradient of the Miami River valley between Dayton and the Ohio River. If the gradient of the bedrock floor of the buried valley is about 3 feet per mile, the test hole at the county-owned well field near the mouth of Holes Creek evidently was not in the deepest part of the channel in that area but bottomed on bedrock on the side of the valley, some 10 or 15 feet above the lowest point.

The shape of the lateral profile of the bedrock valley underlying Dayton cannot accurately be determined from available data. The shape of the valley can be inferred in a general way, however, from what is known about the Deep Stage cycle and the geometry of normal stream development. Deep Stage streams did not attain a graded condition and were still incising their valleys when the cycle ended. The lower part of the principal buried valley at Dayton—that due to Deep Stage cutting—can be assumed, therefore, to have a V-shaped cross section. The sides of the V are asymmetrical, and the slope at any point depends on the relation of the valley to the meanders of the former stream. Typically, a valley is steeper on the outside than on the inside of a meander. Additional generalizations concerning the valley profile are not warranted, owing both to the uncertainties regarding the Teays Stage level and to the scarcity of well records that reveal the depth to bedrock in the Dayton area. The minimum altitude of the bedrock floor of the buried valley in the greater part of downtown Dayton is at or a little below 500 feet. The depth to bedrock at any point in that area therefore approaches 250 feet as a maximum.

#### ILLINOIAN AND WISCONSIN GLACIERS

The Deep Stage drainage system was ended by the advance of the Illinoian ice sheet. Ice of the Illinoian and Wisconsin sheets advanced into and beyond the Dayton area, deranged the drainage lines, filled most of the valleys, some to the point of obliquity, and left the terrain with its present appearance.

The bedrock contours on the geologic map (pl. 1) show the configuration of the buried channels produced by the Teays and Deep Stage streams. Four Deep Stage tributaries to the ancestral Miami River came together in what is now downtown Dayton and formed a wide deep trough, which glacial-outwash materials later filled.

#### SPECIALIZED INVESTIGATIONAL TECHNIQUES

The widespread presence of relatively impermeable layers of till in the sand and gravel aquifers necessitated the development of criteria for their recognition as well as the use of specialized techniques, some of which are not widely understood and warrant discussion here.

The pronounced effects of interbedded till layers on the water-yielding properties of the valley-train deposits, and consequently the consideration that must be made of these layers when wells are located and when aquifers are artificially recharged, require that till and other relatively impermeable deposits be identified during drilling and that these deposits be traced laterally from well to well.

Drillers commonly report till in well logs as "hardpan" or "blue clay" (the second term refers to unweathered material; oxidized till is called "brown clay") and sometimes as "clay and stones" or "clay and gravel." Unfortunately, drillers often find it difficult to distinguish between till deposits, many of which may contain numerous stones and rock fragments in the clay matrix, and so-called "dirty" sand and gravel, which contains much silt and clay. Moreover, the driller's interpretation of the material in which he is drilling may be affected by the sharpness of the bit, the depth of the hole, and the amount of water in the hole. Thus, the accuracy of well logs varies considerably, and the logs of several closely spaced wells may suggest as many different interpretations of the sequence of deposits as there are records. Of course, glacial deposits commonly do change both laterally and vertically over short distances, further complicating the interpretation of drillers' logs. Several methods of identifying till layers are described in the next four sections.

#### STATIC WATER-LEVEL CHANGES

One of the greatest aids to the ground-water geologist in determining the hydrologic properties of the valley-fill deposits, and in identifying areally extensive till layers, is a record of changes in water level made while a well is being deepened. In areas of large ground-water withdrawal, the hydrostatic head in an aquifer overlying a till layer may be several feet higher than the head in a similar aquifer immediately below the till layer. Where this condition occurs the water level in a well being drilled usually changes abruptly when the casing

is driven through the intervening till into the lower aquifer. An illustrative example is shown by the records of several test wells (329-333) drilled in 1931 at the McCall Corp. plant in the west-central part of Dayton. Here abrupt changes in water level of as much as 20 feet are reported in wells drilled through a till layer at depths between about 75 and 105 feet. Unfortunately, these are the only available examples of such a striking change in water levels, since few drillers bother to note these changes as they deepen a well.

#### ELECTRIC (GAMMA-RAY) LOGGING

By far the best method of determining the sequence of beds in the valley-fill deposits and of tracing till layers laterally from well to well is by electric logging of wells, especially gamma-ray logging, which can be done in cased wells. Electric-logging equipment was not available for use in this investigation; however, a few gamma-ray logs, which were very helpful in the geologic interpretation, were furnished by Mr. D. J. Roe of Vandalia, Ohio. Because of the usefulness of gamma-ray logging in water-resources investigations of glacial terrane, a brief description of the method is appropriate here.

Gamma-ray logging techniques are based on the fact that all rocks contain radioactive materials, which emit gamma rays. Generally speaking, limestone and dolomite are much less radioactive than shale, silt, and clay. Glacial till, which in the Dayton area is composed chiefly of clay, is therefore much more radioactive than the associated sand and gravel, which is composed largely of limestone and dolomite fragments. An electrical probe sensitive to gamma-ray emission is lowered in a well. The probe is connected through a cable to a device at the surface that records a curve or log showing the radioactivity, and by interpretation the geologic characteristics of the formations penetrated by the well. Tills are usually distinguishable from sand and gravel on the gamma-ray logs, and the correlation of formations with similar formations in nearby wells can be made with far more confidence than by the use of drillers' logs alone.

Figure 4 shows a representative gamma-ray log, made by Mr. Roe, of a test hole drilled at the site of production well 609, at the Frigidaire Division plant at Moraine City. A geologic interpretation of the gamma-ray log also is shown. On the basis of the gamma-ray log, well 609 was screened at depths of 92-108 feet and 134-150 feet. On test the well was pumped at the rate of 2,000 gpm and a drawdown of only 9 feet resulted, which indicates an exceptionally good capacity. Availability of more gamma-ray logs would have been very helpful to the authors during this investigation.

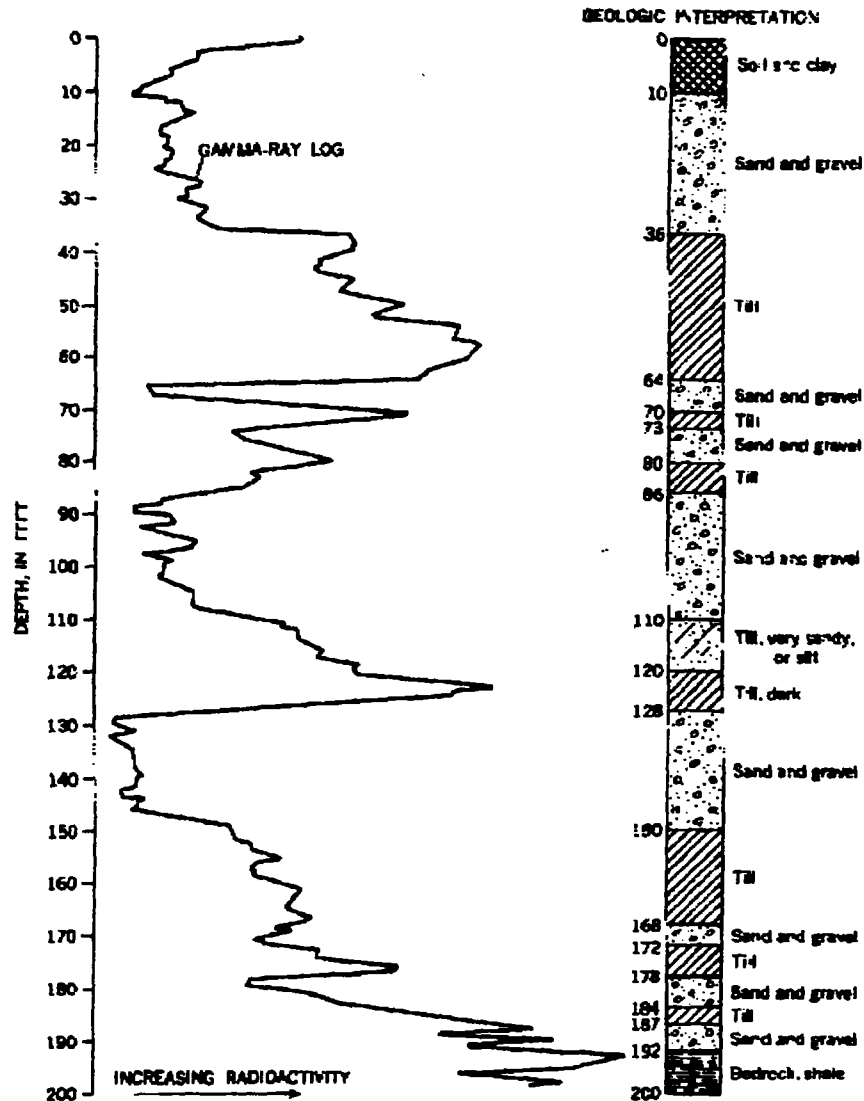


FIGURE 4.—Representative gamma-ray log and geologic interpretation of uncased test hole, drilled at the Frigidaire Division plant at Moraine City.

#### TEMPERATURE-DEPTH RELATIONS

A promising method for identifying interbedded till layers in the Dayton area is that of plotting water-temperature changes in wells at various depths and relating the shape of the resulting temperature-gradient curve to the local geology. Where the circulation of ground water is relatively rapid, such as near large centers of pumping or

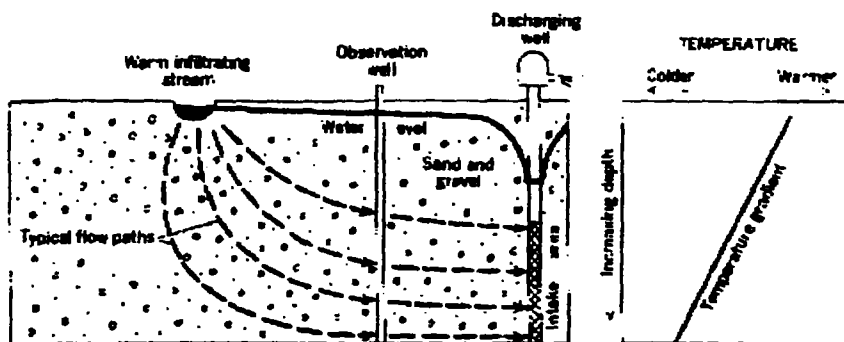
sources of recharge, differences in temperature of water in aquifers that are separated, or partly separated, by till may be large enough to be detected by sensitive, thermistor-type thermometers. The basis of the method is most easily explained by considering examples of temperature gradients to be expected in hypothetical wells drilled under three idealized sets of flow conditions. The explanation is further simplified by specifying that the temperature of the water infiltrating from a source stream is higher than the temperature of the water in the aquifer. In Ohio this condition commonly occurs in late spring and summer.

The first of the three hypothetical flow systems considered is that occurring in a homogeneous heavily pumped sand and gravel aquifer traversed by an infiltrating stream. The temperature of the water in a fully penetrating observation well drilled between the source stream and the well being pumped will decline steadily from the top of the aquifer to the bottom. A plot of water temperature related to depth yields a straight line, as is indicated by the accompanying graph (fig. 5A). This is the simplest of the three hypothetical flow systems.

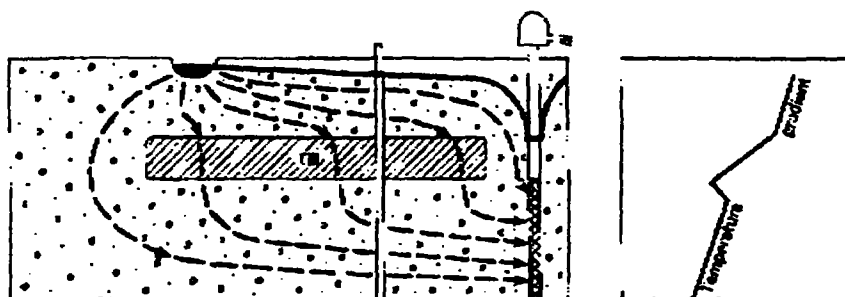
Consider next an otherwise homogeneous aquifer in which a horizontal layer of till of small areal extent occurs (fig. 5B), situated with respect to a large center of pumping so that some water enters the pumped wells after leaking vertically downward through the till, while the remainder of the water flows around the till layer and enters the wells by a more circuitous route. Under these conditions the temperature gradient in the observation well (fig. 5B) will be approximately linear both above and below the till. However, as the diagram shows, that part of the line representing temperatures below the till will be displaced, relative to the temperature-gradient line above the till, in the direction of lower temperature. The position of the till layer in this idealized flow system is indicated by a pronounced "bip" on the temperature-gradient line, caused by the colder water in the till.

The third hypothetical flow system considered is that of two aquifers hydraulically separated by a laterally extensive till layer, through which all recharge to the deeper aquifer must pass (fig. 5C). Under these conditions that part of the temperature-gradient line depicting temperatures beneath the till will be displaced relative to that above the till by the colder water in the till and in the lower aquifer. However, unlike conditions shown in the second example (fig. 5B), the temperature of the water beneath the completely separating till layer will be no higher than that of the water in the till. Thus the temperature in the observation well will always decline with depth, but the rate of decline will increase significantly in the till.

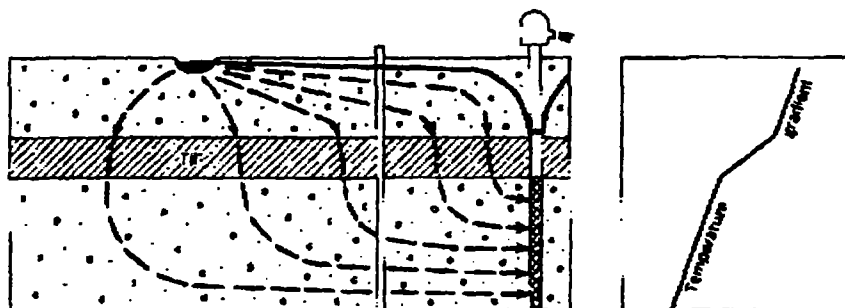




A. Water flowing in homogeneous aquifer results in linear graph



B. Colder water in discontinuous layer of till results in "dip" on graph



C. Aquifers completely separated by till results in displacement of temperature-gradient curve

FIGURE 5.—Idealized ground-water circulatory systems, showing characteristic temperature-gradient curves resulting from infiltration of warm water into relatively cool aquifer under various geologic conditions.

The method of using temperature gradients in wells to identify hydrologic conditions has been tried at only one place in the Dayton area, at the Frank M. Tait Station of the Dayton Power & Light Co. in south Dayton. Temperatures were measured in two 2-inch observation wells (580 and 581) drilled in a well field yielding approximately 5 mgd at the time the measurements were made, in June 1957. At

this time the water in the Miami River was appreciably warmer than the ground water, a condition similar to that specified in the discussion of the hypothetical flow system. The temperature gradients in the two observation wells at the Tait Station indicate that discontinuous layers of till interbedded with the valley-train deposits are present there. (See fig. 6.) This interpretation is borne out by other geologic and hydraulic evidence, described in the section "Character of the Valley-Fill Deposits" and elsewhere in this report.

The temperature-gradient method deserves further testing and refinement under a wide variety of hydrologic conditions and also in representative wells measured repeatedly during various seasons of the year. The growing use of highly sensitive, relatively inexpensive thermistor-type thermometers should result in rapid advancement of what may become a very useful hydrologic technique.

#### SEASONAL TEMPERATURE CHANGES

Another method of determining from water-temperature data the presence or absence of semiconfining beds is based on annual temperature fluctuations in wells. If two wells drilled in a homogeneous and isotropic aquifer and located at equal distances from a source stream receive replenishment principally from the stream, the temperature of the water pumped from the wells will vary with seasonal changes in stream temperature. Graphs relating temperature of water from wells and from streams to time will each have the same general shape. The amplitude of the fluctuations of well-water temperature will not be as great as that of the stream temperature, and the seasonal high and low temperatures of the ground water will lag behind those of the stream. If the two wells are of unequal depth, differences in amplitude of the temperature fluctuations and in time of arrival of seasonal highs and lows from the source stream will be apparent, but the curves will have the same general shape unless the inequalities of depth are very great.

The presence in the water-bearing deposits of a semiconfining bed through which the water must leak, or around which water must flow to reach the wells, will change the shape of the ground-water temperature curve. If at the site of one well the flow of ground water is impeded by a semiconfining bed, the annual-temperature graph for that well will be different from the annual-temperature graph for another well where there is no semiconfining beds. The semiconfining bed will, in general, dampen the seasonal temperature fluctuations, and a relatively flat curve will result. Differences in the annual temperature graphs caused by semiconfining beds were recorded in two wells at the Tait Station of the Dayton Power & Light Co. (fig. 7).

## CHARACTER OF THE VALLEY-FILL DEPOSITS

The wide valleys at Dayton, which were cut deeply into the bedrock by streams of the Teays and Deep Stage drainage systems, were filled during the ensuing glacial stages principally with sand and gravel, laid down as valley train by melt water, and with till which occurs as lenses and layers interbedded with the sand and gravel deposits. Though constituting a relatively small part of the valley-fill deposits, the till is a major hydraulic factor because it slows recharge to the deeper wells.

Glacial ice melts unevenly and at varying rates. Moreover, periods of melting commonly are interspersed with intervals of relative cold during which glaciers may temporarily resume their growth. The valley-train deposits were laid down under variable conditions, and although at a distance they seem generally uniform, alternate layers of silt, sand, and gravel, representing a wide range of grain sizes, are visible up close. Layers of coarse gravel may be sharply bounded above and below by beds of markedly finer material, and, in many places, beds of coarse gravel may grade laterally into finer material over comparatively short distances.

Goldthwait (1959, p. 206) described as follows the way in which a typical valley-train deposit is formed:

Wherever a glacier ends in a region which slopes away from the ice, the waters which issue from one or more tunnels in the ice edge head down the nearest valley lowland. Many million gallons are produced on warmest days. Coming from the basal ice, the water is milky with the rock flour of glacial till and it has a full bed load of sand and gravel. In fact, more tons of particles are fed into the stream at the glacier than ever reach the lake or sea, so there must be constant addition to the surface of the plain. Some load is dropped on each bar thus filling up the shallow channel and causing the water to spill over to the right or left and start an additional channel. All glacial outwash rivers become braided by dividing into many channels each ten to 100 feet wide and one to ten feet deep. The water runs nearly flush with the surface. Most of the coarsest cobble part of the load gets left on the first few upstream bars, but in their place the water gathers some smaller pebbles already there. . . . When one side of the valley plain builds ten to 20 feet higher, the braided currents shift to the low side of the valley. The resulting "valley-train" is smooth with only minor little scarps (five to 20 ft.) and abandoned channels. . . . This was the scene in most south-flowing valleys in Ohio as the ice retreated.

The events that Goldthwait describe were repeated several times in the Dayton area, at least once during each of the major glacial stages and substage. Each time the glaciers melted, the principal valleys were partly filled with sand and gravel, and during each of the long interglacial intervals—each lasting several tens of thousands of years—streams similar to those that now occupy these valleys began their slow work of erosion and removal of the deposits over which

they flowed. During the long interval between the Illinoian and Wisconsin glacial stages, which may have lasted more than 100,000 years (Goldthwait, in Norris and others, 1948, p. 28; Rubin, 1960, p. 289), most of the material deposited by the Illinoian and earlier glaciers probably was removed from the bedrock valleys by stream erosion.

With the onset of the Wisconsin glacial advance, conditions that had prevailed during the preceding interglacial interval changed. Except during the few warm days in summer, rivers dwindled or stopped flowing altogether, and their place was taken eventually by tongues of ice, which moved southward in advance of the main ice mass. These ice tongues, or valley glaciers, are mainly responsible for the extensive deposits of till that occur nearly everywhere in the valley-train deposits. In central Dayton, where four valley glaciers coalesced, the interbedded till deposits are relatively thick and extensive.

In some parts of the Dayton area, well-defined till sheets, buried by 20-60 feet of sand and gravel, extend almost entirely across the major valleys and separate the valley-train deposits into two or more distinct aquifers. For example, at Rohrer's Island, in the Mad River valley, wells of the Dayton municipal well field tap two aquifers, one lying above and the other below a layer of till that ranges in thickness from about 11 to 60 feet (Norris, 1959, p. 3).

Drillers' logs, gamma-ray logs of wells, and water-level data show that conditions similar to those at Rohrer's Island prevail generally in the major river valleys of the Dayton area. The valley-train deposits, in most places, are separated into an upper aquifer and a lower aquifer. Section *A-A'* (pl. 3), extending along the middle of the Miami River valley from the mouth of Holes Creek northward to north Dayton and thence up the Mad River valley to Huffman Dam, and sections *B-B'*, *C-C'*, *D-D'*, and *D-D''* (pl. 3), extending across the valley, show clearly a zone as much as 80 feet thick, predominantly of till, interbedded with sand and gravel deposits. (See pl. 1 for location of geologic sections.) In places, this till-rich zone is made up of well-defined areally extensive till sheets; elsewhere it consists of numerous lenses and irregular masses of till grouped closely together at approximately the same altitude. The till is more irregular in distribution near the sides of the valleys than in the central part.

In small areas, notably in the Mad River valley immediately below Eastwood Park, the till either is absent from the sand and gravel deposits or consists only of a few scattered lenses. Elsewhere, there are small openings in otherwise extensive till sheets; these probably repre-

sent stream channels cut through the till when it was exposed at the surface. These openings or channels are indicated by the absence of till in one or two records of several closely spaced wells.

The upper surface of the till-rich zone lies generally 30-50 feet below the land surface in downtown Dayton. The base of the zone, which is much more irregular than the upper surface, ranges from about 60 to 125 feet below land surface. These levels are somewhat arbitrary, as the sand and gravel deposits both above and below the till-rich zone contain scattered lenses and masses of till that make it difficult in places to correlate the deposits from well to well.

Locally in the Miami River valley in central and northern Dayton, and more extensively in the Mad River valley downstream from Findlay Street, the till-rich zone consists of two till layers, separated by several feet of sand and gravel. The upper till layer generally is thinner and less extensive than the lower till layer. Although locally the intervening sand and gravel constitutes a separate aquifer, it is herein considered part of the upper aquifer.

The sequence of late Pleistocene events described by Goldthwait indicates that the till-rich zone and the overlying sand and gravel probably are associated with the late Wisconsin substage. Therefore, the sand and gravel that underlies the till-rich zone was probably deposited during the retreat of the early Wisconsin glacier. The early Wisconsin glacier also deposited till on or only slightly above the bedrock in most of the Dayton area, except in the relatively narrow Deep Stage channels, which in a few places probably contain sand and gravel left by a still earlier glacier.

The interval between the end of the early Wisconsin substage and the beginning of the late Wisconsin substage was not long enough for the streams to erode from the valleys much of the early Wisconsin sand and gravel deposits. Thus, when the late Wisconsin ice sheet advanced to the Dayton area, it moved down the valleys over early Wisconsin sand and gravel deposits of considerable thickness.

The relatively shallow till layer, which composes part of the till-rich zone in the Miami River valley in certain areas in central and northern Dayton and in the lower Mad River valley, probably was deposited during the local readvance of the late Wisconsin glacier, described by Goldthwait (Norris and others, 1948, p. 34). In most places these shallower till deposits are thinner and less extensive than those associated with the main advance of the late Wisconsin glacier. The glacier moved a relatively short distance when it readvanced, and, generally, the ice transported less material than it did during the main advance. However, in central Dayton the shallower till is thicker and more extensive than the lower till.

The till-rich zone cannot be separated into an upper and a lower till layer in two areas of the Miami River valley: (1) central Dayton and (2) between Dayton and the mouth of Holes Creek. However, the till-rich zone in these areas may actually consist of two tills, one lying directly upon the other. This is suggested by color changes in the till, noted in several drillers' logs. These color changes indicate not only the usual sequence of yellow, oxidized till overlying blue, unweathered till, but also the presence in a few places of yellow till beneath blue till. The latter sequence could have resulted from the deposition of younger till on the surface of slightly older, oxidized till. However, the yellow color of the till at the base of the till-rich zone also could have resulted from chemical changes caused by the circulation of ground water.

The log of a typical drilled well near the Miami River in the Dayton area shows a few feet of soil and alluvial material<sup>1</sup> near the surface. Beneath the soil and alluvium is 30-50 feet of sand and gravel, overlying about 30 feet of till. The till, which most drillers would call either clay and gravel or hardpan, overlies 50 or 60 feet, perhaps more, of sand and gravel. The lower sand and gravel stratum also overlies till, and this basal till, 10-20 feet thick, overlies the shale and limestone bedrock. This hypothetical and highly generalized well log reflects a simplified geologic section through the valley-fill deposits.

#### MIAMI RIVER VALLEY SOUTH OF DAYTON

##### DRYDEN ROAD WELL FIELD OF MONTGOMERY COUNTY SANITARY DEPARTMENT

South of Dayton near the mouth of Holes Creek, at the Montgomery County Sanitary Department well field on Dryden Road, four wells (M-10, M-11, M-12, M-13) penetrate deposits of till as much as 15 feet thick interbedded with the sand and gravel deposits. The till deposits range in depth from 45 to 75 feet and probably consist of a group of closely spaced lenses rather than a continuous layer. The till generally separates the sand and gravel deposits into an upper and a lower aquifer; however, recharge to the lower aquifer in this area would be expected to be relatively rapid, from water percolating downward through openings between the individual till masses. The Dryden Road well field is favorably located above the Deep Stage channel, where the sand and gravel deposits are relatively thick. Bedrock is about 230 feet below land surface and about 490 feet above sea level.

<sup>1</sup> Alluvium consists chiefly of sand, clay, and silt, deposited by present-day streams when they overflow their banks.

**MIAMI SECRES WELL FIELD OF MONTGOMERY COUNTY SANITARY DEPARTMENT**

The Montgomery County Sanitary Department is developing a new well field on the west side of the Miami River just below the mouth of Holes Creek in the Miami Shores area. In 1960 three production wells (M-14, M-15, and M-16) were drilled to depths ranging from 150 to 176 feet. A till deposit about 5 feet thick at a depth of about 68 feet was reported in all three well logs. This till is correlative with the till interbedded with the sand and gravel deposits at the nearby Dryden Road well field.

**LAMME ROAD WELL FIELD OF MONTGOMERY COUNTY SANITARY DEPARTMENT**

Less than a mile northeast of the Dryden Road well field is the Lamme Road well field, also part of the water-supply system of the Montgomery County Sanitary Department. Here till deposits of various thicknesses are reported at depths ranging from 40 to 81 feet, corresponding generally to the position of the till-rich zone. The till deposits are discontinuous; they are reported in the logs of only five of the nine drilled wells in the area (wells M-1 to M-9). Some logs report "dirty gravel" at the altitude of the till-rich zone.

Above the till-rich zone the sand and gravel deposits are relatively fine grained and are mixed with clay. Below the till-rich zone the deposits are "cleaner" and coarser grained, ranging from sand to coarse gravel and boulders. The deeper sand and gravel deposits enclose a lens of clay, the top of which is reported in the logs of several wells at depths ranging from about 90 to 125 feet. This clay bed, though not reported in all the logs, is 35 feet thick in places. A sample taken from well M-6, between depths of 91 and 126 feet, was described by Mr. John Eschliman of the Ralph L. Woolpert Co. as a very dense clay free of stones. This clay probably was deposited in the waters of a small lake. Though of limited extent, the clay adversely affects the yields of wells at the Lamme Road well field.

The sand and gravel deposits in both the upper and the lower aquifers at the Lamme Road well field contain a high proportion of fine-grained material, which has contributed to problems of well development and maintenance. In the 10-year life of the well field two wells have been redrilled and all the other wells have been redeveloped. Specific capacities of the wells originally ranged between about 40 and 85 gpm per ft. The specific capacities of two wells were increased to more than 100 gpm per ft. by redrilling them and installing longer well screens.

Geologic section *B-B'* (pl. 8), which is drawn across the Miami River valley through the Lamme Road well field and the area of the Moraine plants of the Frigidaire Division, General Motors Corp.,

shows the general character of the valley-fill deposits. Recharge from the upper aquifer to the lower aquifer is relatively rapid at the Lamme Road well field, as it is at the Dryden Road well field, because of the discontinuity of the deposits in the till-rich zone.

#### FRIGIDAIRE DIVISION, GENERAL MOTORS CORP. WELL FIELD

West of the Lamme Road well field, in the vicinity of the Frigidaire Division plants, the till deposits of the till-rich zone are continuous over a large area. At the Frigidaire plants all but 1 or 2 of 26 well logs show relatively thick till within a zone whose upper surface ranges in depth from about 30 to 40 feet and whose lower surface ranges in depth from about 80 to 90 feet. The till in this zone ranges in thickness from about 5 to 70 feet; the median thickness is about 20 feet. (See pl. 2.) The till, which occurs chiefly as a widespread sheet, significantly reduces recharge to the lower aquifer at the Frigidaire plant.

Evidence of the hydraulic separation of the upper and lower aquifers is shown by differences in water level in wells open above and those open below the till-rich zone. This evidence was obtained indirectly in March 1959 during repair of well 553, which was temporarily taken out of service because of a hole in the casing. The well is screened between depths of 95 and 125 feet, immediately below the till-rich zone. The hole in the well casing, which was detected by plant engineers when the well began yielding warmer water, was 44 feet below the land surface, at or near the top of the till-rich zone. In repairing the well a plug was placed in the casing a few feet below the hole to stop flow between the upper and lower parts of the well. The plug was left in place overnight, during which time the water level rose to 25.1 feet below the top of the casing, or 4.3 feet higher than it had been before the plug was put in. This shows that the water table in the upper aquifer was a few feet higher than the piezometric surface in the lower aquifer. Water pumped from the lower aquifer at the Frigidaire Division plants must either leak downward through the till of the till-rich zone or flow laterally to the wells from more distant areas where the till deposits are discontinuous or absent.

#### SOUTH DAYTON

##### DAYTON POWER & LIGHT CO. WELL FIELD, FRANK M. TAIT STATION

The Frank M. Tait Station of the Dayton Power & Light Co. (formerly the Miller's Ford Sta.) is just within the southern limits of Dayton, on the south bank of a wide meander in the Miami River not far from Carillon Park. Till, corresponding in altitude to the till-rich zone, is reported in 10 of 12 logs of wells drilled in the vicinity of



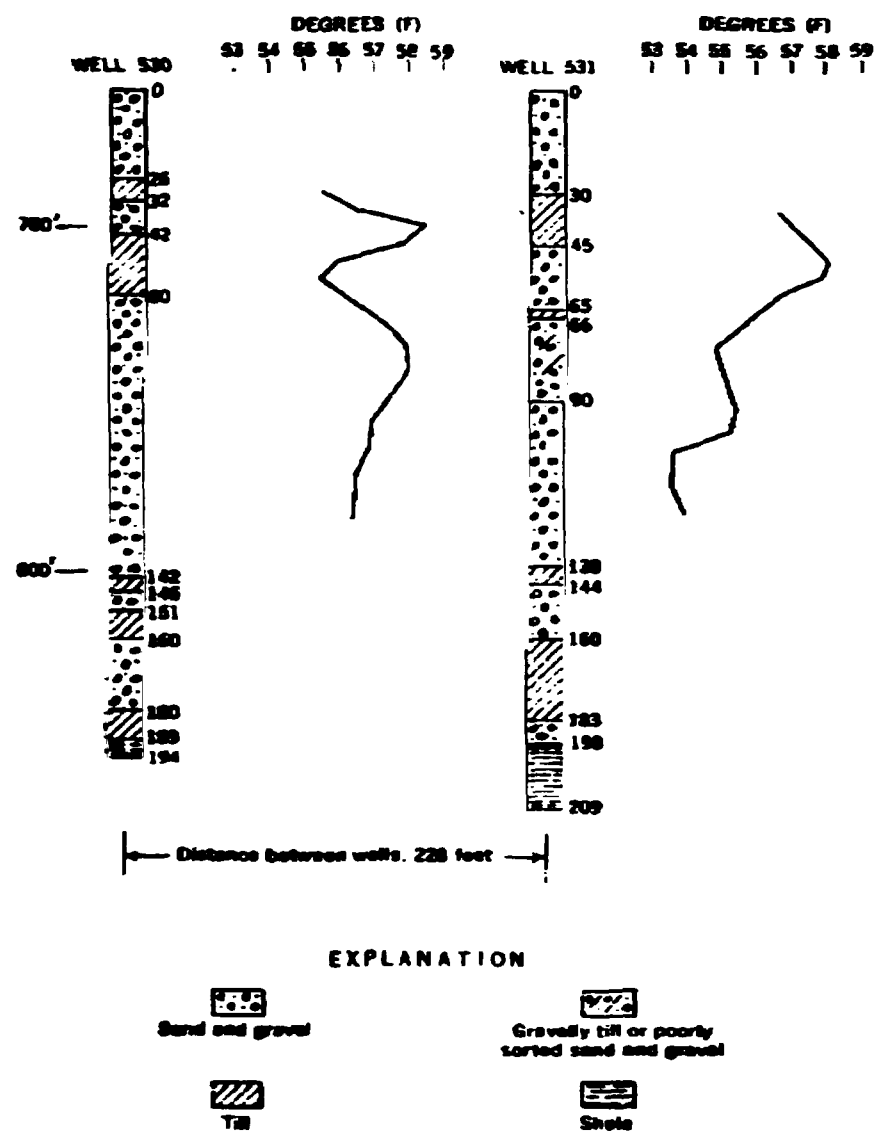
the Tait Station; however, there is wide variation in the reported depths of the till deposits and a range of 3-20 feet in their thickness. The till-rich zone evidently consists chiefly of closely grouped, irregular lenses of till, rather than a continuous and widespread sheet. (See geologic section A-A', pl. 3.) The logs of well 524 and the preliminary test hole (well 607) drilled at the same site show almost no till at the position of the till-rich zone.

Graphs of temperature gradients measured in wells 530 and 531 provide additional evidence of local gaps in the till-rich zone. The graphs show that some water flows through these openings in moving from the upper to the lower aquifer. Figure 6 shows drillers' logs of wells 530 and 531, beside which are plotted the respective temperature-gradient curves. Except for the somewhat anomalous lower part of the temperature-gradient curve for well 531, which suggests the presence of an unlogged till deposit, zones of colder water closely correspond in depth to deposits of till as logged by the driller, while warmer water is associated with the intervening or underlying sand and gravel deposits. The temperature in the wells was measured in June 1957, when the water in the stream was warmer than the ground water. The water in the till had not been affected as much by circulation of water derived from stream infiltration as had the water in the permeable sand and gravel deposits, indicating that much water flowed around the till to reach the lower aquifer. Had all the water entered the lower aquifer by leakage through the till it would have been no warmer than the water in the till itself. The zones of warmer water in well 530 reach nearly the same maximum temperatures, while of the two warmer zones in well 531 the lower zone is much cooler than the upper zone. This indicates that the movement of water from the upper to the lower aquifer was taking place more rapidly in the vicinity of well 530, where the till is absent locally, than in the vicinity of well 531, where the flow was chiefly by leakage through the till.

Despite the fact that openings occur locally in the till-rich zone at the Tait Station, this zone is generally effective in retarding the movement of water from the upper to the lower aquifer. A pumping test made on well 524 in April 1956 showed that the till was highly effective in hydraulically separating the upper and lower aquifers.

Annual temperature graphs of ground water from two wells at the Tait Station, compared to a similar graph of temperature in the Miami River, also show that the till-rich zone is hydraulically effective in separating the upper and lower aquifers. The graph (fig. 7) of the annual water temperature in well 521, which is 65 feet deep and screened near the bottom of the upper aquifer, reveals seasonal fluctu-

ations much like those occurring in the Miami River. In contrast, the annual temperature graph of water from well 524, which is 155 feet deep and screened in the lower aquifer, is nearly flat. If no semi-confining bed existed in the area, seasonal fluctuations would be ap-



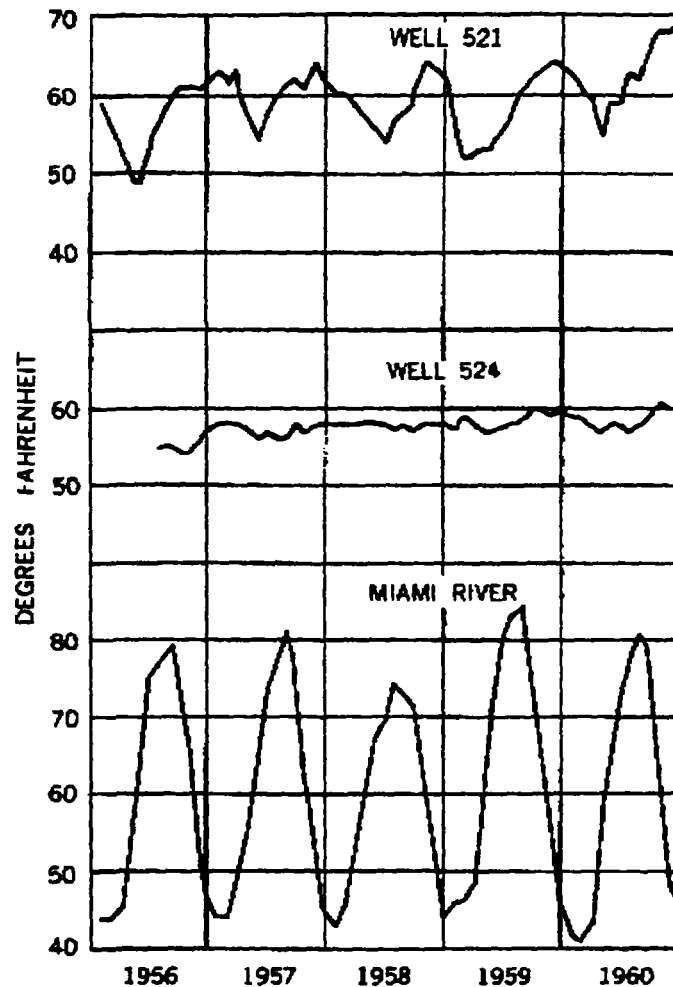


FIGURE 7.—Graphs of annual temperature of water in wells at the Tait Station of the Dayton Power & Light Co., compared with that of the Miami River.

parent in the graph from well 524, which is much closer to the river than is well 521.

In summary, at the Tait Station of the Dayton Power & Light Co., the till-rich zone consists chiefly of lenses and discontinuous masses of till. Some wells have been drilled nearly to bedrock without cutting any significant till deposits. Recharge to wells screened below the till-rich zone is by leakage through the till deposits and by the flow of water around and between the lenses and masses of till. The area has

proved an excellent one for the development of large ground-water supplies.

NATIONAL CASH REGISTER CO.-MCCALL CORP. AREA

Geologic section C-C' (pl. 3) shows the character of the valley-fill deposits along an east-west line extending across the Miami River valley from the vicinity of the McCall Corp. plant in southwest Dayton to a point east of the National Cash Register Co. plant.

The till-rich zone in the vicinity of the McCall Corp. plant is about 80 feet thick and lies between the approximate depths of 75 and 105 feet. Large differences are noted between water levels in wells open above the till and in wells open below the till.

In five test holes (329-333) drilled at the McCall Corp. plant in 1951, the water level during drilling ranged between 33 and 40 feet below the surface until the wells were deepened below the till-rich zone. When this was done the level dropped abruptly to depths ranging between 50 and 58 feet. Thus, the till-rich zone is highly effective, hydraulically, in separating the valley-fill deposits into two principal aquifers. There is evidence that the till may contain a lens of sand and gravel, as indicated on the cross section.

The till-rich zone shown in geologic section C-C' is projected laterally across the valley largely on the basis of records of wells drilled at the Himes Bros. Dairy (well 321), the Dairy Division of the Kroger Co. (well 324), the Sunshine Biscuit Corp. (well 360), and the National Cash Register Co. plant. At the Sunshine Biscuit Corp., for example, wells are screened in the lower aquifer between depths of 75 and 115 feet, beneath a till-rich zone approximately 25 feet thick.

At the National Cash Register Co. plant, which lies near the east side of the Miami River Valley and also near the east side of the underlying bedrock valley, till constitutes a large part of the valley-fill deposits. The till deposits range widely in depth and thickness, occurring mainly as irregularly distributed lenses and masses. Nearly all the company-owned wells are screened below the till; however, the separation of the sand and gravel deposits into an upper and a lower aquifer probably is not as clear cut as is indicated on plate 3. Most recharge to the wells is by percolation between or around the till deposits. This is shown by the fact that the water level in observation well Mt-3, at the northwest corner of Stewart Street and Patterson Boulevard, on the east bank of the Miami River, quickly responds to changes of stage in the nearby river as well as to variations in the pumping rates at the plant.

## CENTRAL DAYTON

In much of the central part of Dayton the till-rich zone is composed of two tills—an upper, relatively thick bed, and a lower, thinner bed, separated by 20–35 feet of sand and gravel. The upper till is more extensive than the lower, though both can be correlated from well to well over considerable distances. A few wells have been screened between the two tills in what is considered, somewhat arbitrarily, to be part of the upper aquifer.

## AETNA PAPER CO. (WELLS 301–304)

The upper till of the till-rich zone is about 25 feet thick and lies between depths of 40 and 65 feet. The lower till is approximately 15 feet thick and lies between depths of about 95 and 110 feet. Thus, the tills are separated by about 35 feet of sand and gravel. Both tills correlate closely with similar till deposits at the Longworth Street Station of the Dayton Power & Light Co., more than a third of a mile east of the Aetna Paper Co. wells.

The Aetna Paper Co. formerly had eight wells 40–42 feet deep screened above the upper till. These wells went dry, and deeper wells were drilled 80–100 feet deep and screened between the upper and lower tills. Still later, the present wells were drilled through the lower till and screened in the lower aquifer.

## DAYTON POWER &amp; LIGHT CO., LONGWORTH STREET STATION (WELLS 23–26)

The upper till of the till-rich zone is approximately 30 feet thick and occurs between depths of about 40 and 70 feet. The lower till is reported between depths of about 100 and 110 feet. These till deposits, which together constitute the till-rich zone, correlate closely with similar deposits at the Aetna Paper Co. plant.

The two principal production wells (23 and 24) at the Dayton Power & Light Co. plant are screened in the lower aquifer between depths of 144–172 feet and 120–135 feet, respectively. Temperature measured in well 24, the shallower well, in June 1957, at 5-foot-depth intervals, showed a slight, though abrupt, decrease below the depth of 110 feet, corresponding to the base of the till-rich zone.

## DELCO PRODUCTS DIVISION, GENERAL MOTORS CORP. (WELLS 28–31)

Conditions at the Delco plant are unlike those that prevail generally in central Dayton in that here there are no well-defined till layers. Of the logs of seven wells drilled at this site, five show till deposits of varying thickness at depths of 40–95 feet, the approximate position of the till-rich zone. Till is not reported in the other two well logs, which suggests that the till-rich zone is composed either of discontinuous

lenses or of an irregular sheet through which channels were cut before deposition of the upper sand and gravel aquifer.

The north-central downtown area, in which the Delco plant is located, lies at the confluence of three buried valleys. At various times in the Pleistocene Epoch, valley glaciers coalesced in this area, and the rock materials that they carried were commingled to form a complex mass of till. Likewise, when the glaciers retreated, melt waters may have produced at their junction a variety of unusual erosional and depositional features. For example, some of the well logs at the Delco plant report deposits of fine sand of considerable thickness. In the log of well 35, fine to very fine sand is reported below the depth of 126 feet, extending nearly to the bedrock surface at the depth of 200 feet. Fine sand, often called "quicksand" by well drillers, is rarely more than 15-25 feet thick in the Dayton area and occurs most commonly just beneath the till-rich zone.

#### DAYTON POWER & LIGHT CO., THIRD STREET STATION (WELLS 12-21)

Interbedded till deposits of variable thickness are reported in the logs of wells drilled at the Third Street Station. Till occurs in the sand and gravel deposits at depths of about 25-60 feet and 80-110 feet. One or two early wells were screened between the tills, at depths of 60-80 feet, but the present wells are screened beneath the lower till in the lower aquifer at depths of 115-145 feet.

#### NORTH DAYTON AREA

Geologic sections *D-D'* and *D'-D''* (pl. 3) illustrate the character of the valley-fill deposits in the northern part of Dayton. Section *D-D'* is based on meager data, chiefly that from wells drilled at the plants of the Dayton Castings Co., Premier Rubber Co., and Chrysler Airtemp Sales Corp., but it is presented to show that in this area, too, the valley-fill deposits evidently are separated by till into an upper and a lower sand and gravel aquifer, similar to generally prevailing conditions in the Dayton area.

#### MIAMI RIVER WELL FIELD AREA

Geologic section *D'-D''* is drawn northward from the corner of Troy and Valley Streets through the Miami River well field of the city of Dayton, on the west bank of the Miami River approximately  $3\frac{1}{4}$  miles northeast of the center of Dayton. Logs of wells drilled at the Miami River well field clearly show the till-rich zone, which separates the sand and gravel deposits into an upper and a lower aquifer. The upper aquifer, lying immediately beneath the soil and river alluvium, consists of 30-40 feet of coarse sand and gravel, into which the Miami River has cut its channel. Beneath the upper

aquifer are deposits of till, reported in nearly all the well logs, constituting a well-defined till-rich zone between depths of about 40 and 90 feet.

Beneath the till-rich zone at the Miami River well field are 50-70 feet of coarse sand and gravel. The lower sand and gravel aquifer is generally underlain by till, which in turn overlies the shale bedrock. Most wells are screened between depths of about 65 and 130 feet, as the test-hole records show that in this interval the sand and gravel deposits are coarsest.

#### MAD RIVER VALLEY

Geologic section A-A' (pl. 3) shows that in the Mad River Valley the till-rich zone consists of two tills, the thickest and most extensive of which lies about 40-80 feet below the land surface. A minor, less extensive till zone lies a few feet below the riverbed and, in a small area above the Keowee Street Bridge, constitutes a local confining bed, similar to that formed generally by the deeper till deposits. Elsewhere in the Mad River Valley, the upper till is represented chiefly by scattered lenses.

#### KEOWEE STREET AREA

In the Mad River Valley in the vicinity of Keowee Street, the upper till forms a local confining bed, similar to that formed by the deeper and more widespread till which generally separates the upper and lower aquifers. Evidence of this relatively shallow confining bed is shown by the fact that water in several wells of the waterworks "old main group" or "river wells" occurs under sufficient artesian pressure to flow. These river wells range in depth from 80 to 88 feet and are screened above the deeper till layer. When the wells were drilled in 1887, artesian pressure was great enough that the wells flowed 3 feet above river level. In an early history of Dayton, Steele and others (1889, p. 214) stated that:

During the months of July and August 1887 the board of waterworks trustees constructed, in the bed of Mad River, east of Keowee Street, a series of tube wells, 30 in number, eight inches in diameter, and at an average depth of 40 feet. The water from these wells flows of its own accord, rising above the tops of the wells and above the level of Mad River an average height of three feet.

According to Mr. Charles Stout, well-field superintendent, some of these old wells were opened in 1960 during the laying of a pipeline near Keowee Street, and water still flowed from the wells after 73 years, although under much less artesian pressure.

The artesian head producing flow in the old river wells cannot be derived from the head in the lower aquifer, as the piezometric surface in that aquifer, shown by water-level measurements in well C-47 at the municipal softening plant, fluctuates between about 20 and 25 feet

below the land surface. The river wells tap a local artesian aquifer in which water is confined by the shallow layer of till. Till exposed in the bed of the Mad River about  $1\frac{1}{2}$  miles above Keowee Street and about half a mile below Eastwood Park, near the Baltimore & Ohio Railroad bridge, may represent the edge of the till sheet that forms the confining bed in the vicinity of Keowee Street. If so, the artesian pressure in the old wells probably originates in the area of Eastwood Park, where the river is about 3 feet higher than it is in the vicinity of Keowee Street.

#### FINDLAY STREET AREA

The valley-fill deposits in a mile-long segment of the Mad River Valley centering near the Findlay Street Bridge are worthy of special note relative to the availability of ground water. Near the Mad River in much of this area the till-rich zone evidently is absent. This is shown by the records of city-owned wells C-44, C-45, and C-46, drilled on or near the levee on the south bank of the Mad River, and the record of well 217, which is 141 feet deep, drilled at the Dayton Rust Proof Co. The driller's report on well 217 states simply, "gravel all the way," which is interpreted to mean that no till deposits were cut.

Although this meager evidence can hardly be called conclusive, it clearly points to the possibility that the Findlay Street area may become important in future water-resources development involving either the withdrawal or the artificial recharging of large quantities of ground water. If the till-rich zone is absent over a sizable part of this mile-long area, water can percolate from the surface to the deeper parts of the aquifer much more readily than at most other places in the Dayton area. The presence of numerous gravel pits from which, as from the Mad River, infiltration can originate makes the area doubly attractive as a possibility for large-scale water-resources development.

#### ROHRERS ISLAND AREA

Test drilling on and near Rohrer's Island was begun in 1928, and since that time the Dayton municipal water department has drilled scores of test holes and production wells. About 1946, Mr. W. W. Morhouse, then director of the Dayton Water Department, estimated the number of test holes and wells drilled on Rohrer's Island at more than 400. Since 1946 several additional test holes and production wells have been drilled on or near the island.

Judging from the large number of drill-hole records available, one might assume that the character of the valley-fill deposits in the Rohrer's Island area is known in great detail. This is indeed true compared to our knowledge of the deposits in many other areas of



comparable size in the Miami River and Mad River valleys. Significant gaps in our knowledge remain, however, because most of the wells and test holes drilled on and near Rohrer's Island were relatively shallow and did not penetrate into the lower aquifer. Moreover, nearly all the drilling was concentrated in a few small areas near the river, leaving untested relatively large areas between the Mad River and the edges of the valley. Also, many of the drillers' logs are sketchy and inadequately describe the formations. Despite these deficiencies, there remains a wealth of information on which to base a description of the valley-fill deposits in the Rohrer's Island area.

In that part of the Mad River valley extending from the vicinity of Huffman Dam down at least as far as Tates Hill, the valley-fill deposits are effectively separated by a till-rich zone into an upper and a lower aquifer, typical of conditions generally in the Dayton area. (See geologic section A-A', pl. 3.) This fact has been recognized by waterworks officials for many years. Indeed, it is probable that the aforementioned area was the first in which the separation of the sand and gravel deposits into an upper and a lower aquifer was considered as a factor in well development. The water in the lower aquifer was known to be harder and higher in iron content than the water in the upper aquifer, and before Dayton had a municipal water-treatment plant few wells were drilled to the lower aquifer and these were seldom pumped. After 1953, when Dayton built a treatment plant, more wells were drilled in the lower aquifer near Rohrer's Island and these became major sources of supply. The drilling of the deeper wells also yielded much valuable information on the character of the valley-fill deposits.

In the vicinity of Rohrer's Island the upper aquifer is about 65 feet thick and the lower, about 50 feet thick. The till-rich zone which separates the aquifers ranges in thickness from about 11 to 50 feet (Norris, 1959, p. 3; Norris and others, 1948, p. 52). The upper aquifer contains interbedded lenses of till in the vicinity of Rohrer's Island. Farther downstream, between Harshman Road and Tates Hill, the shallow till deposits can be correlated from well to well and evidently constitute a widespread, nearly continuous sheet lying 20-30 feet below the land surface. The till sheet that forms the shallow confining bed in the vicinity of Keowee Street is no doubt correlative with the shallow till deposits at Rohrer's Island.

At Rohrer's Island the shallow till deposits impede recharge from the Mad River to wells drilled in the upper aquifer. The wells of highest specific capacity are located in areas where these till deposits are thin or absent (fig. 8).

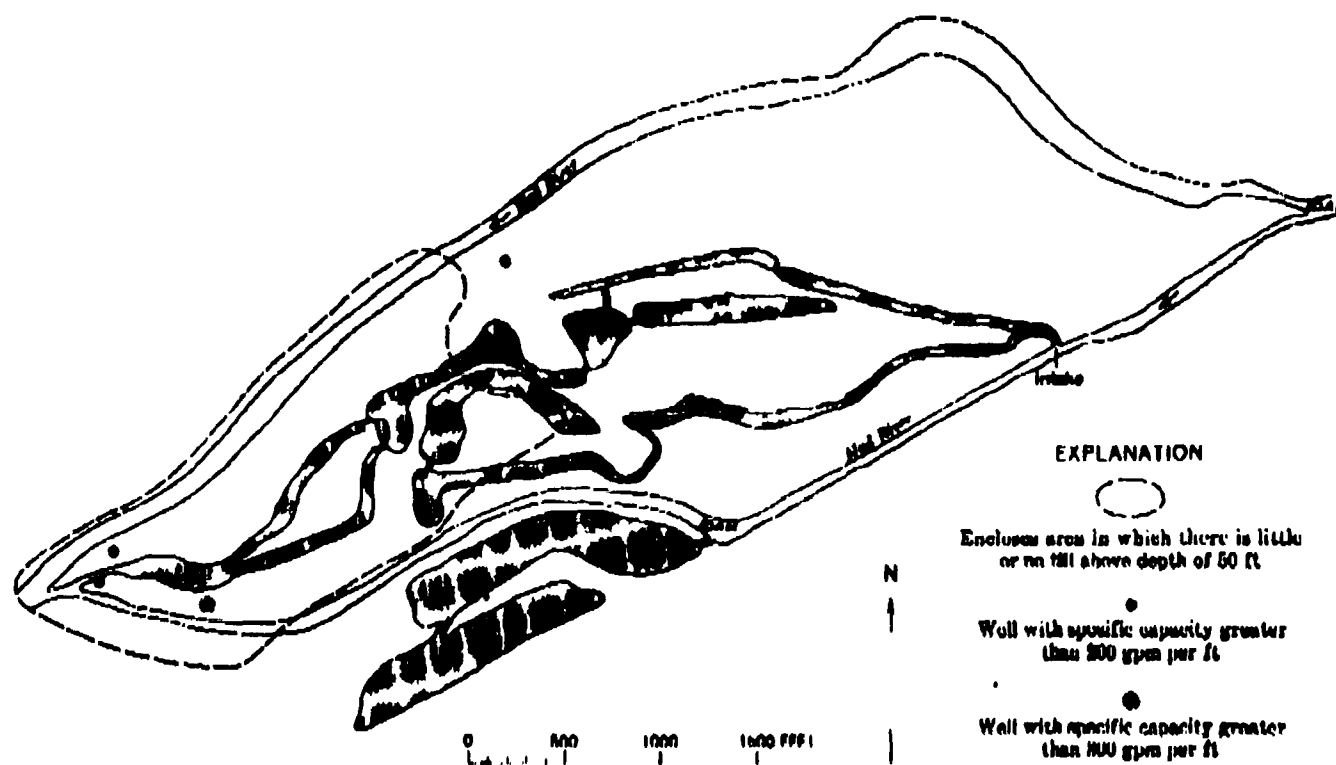


FIGURE 8.—Shallow till deposits, wells of high specific capacity, and recharge ponds, Rebers Island.

### HYDRAULIC PROPERTIES OF THE VALLEY-FILL DEPOSITS

The functioning of the natural hydraulic system, of which the valley-fill deposits are a principal component, is basically simple. Partly filling the preglacial bedrock valley that passes through the heart of Dayton is some 150-250 feet of glacial deposits, consisting chiefly of sand and gravel, over which the Miami River and its tributaries flow. Below the depth of a few feet the sand and gravel generally are saturated, and wells drilled into these permeable deposits yield large quantities of water. As water is pumped from storage in the deposits it is replenished principally by infiltration through riverbeds. Some recharge is derived also from rainfall that enters the ground in the vicinity of the pumped wells, and from ground water diverted to the wells by interception or capture of its natural flow from the uplands into the streams.

Although simple in principle, the mechanics of this hydraulic system are complicated in detail. Differences in permeability of the sand and gravel deposits from place to place both laterally and vertically, and variations in streamflow and in the rate of stream infiltration, as well as the distribution of pumpage, are among the factors that must be considered in evaluating the ground-water resources.

Of considerable importance too are the effects of the till-rich zone, which generally separates the valley-fill deposits into an upper and a lower aquifer and impedes recharge to the lower aquifer, in which nearly all the wells are screened. The till-rich zone confines water in the lower aquifer under artesian pressure. In the upper aquifer the water generally is not under pressure but occurs under water-table conditions.

### ARTESIAN AND WATER-TABLE CONDITIONS

The upper aquifer is similar to a surface reservoir such as a lake, and the water table or upper surface of the saturated part of the aquifer is analogous to the water surface in the lake. In the lower (artesian) aquifer no true water table or free surface exists. However, the levels to which water will rise above the semiconfining bed in tightly cased wells form an imaginary, piezometric (pressure-indicating) surface, which in a sense is analogous to the water table in the upper, unconfined aquifer.

When a well is pumped, the water level is drawn down in the well and in a cone-shaped area of the aquifer around the well. If the aquifer is homogeneous and of large areal extent, water flows to the well from all directions in response to the hydraulic gradients created by pumping. If the well is drilled in an unconfined aquifer, water

flows toward the well by gravity and drains from storage as the cone of influence spreads. Dewatering the aquifer slows the effects of pumping, and the drawdown that occurs within any specified time is smaller than it would have been had little or no stored water been available. When a well in an artesian aquifer is pumped the aquifer is not drained by gravity, except perhaps in the immediate vicinity of the well if the water level is drawn below the upper confining bed. As only a little water is made available from storage, by elastic compression of the aquifer and expansion of the water, the cone of influence must extend over a greater area to induce the amount of water being pumped to flow into the well, and the effects of pumping are quickly transmitted from one part of the aquifer to another.

Consider the effects of pumping each of two identical wells screened in sand and gravel deposits having permeabilities and thicknesses typical of such deposits in the Dayton area. Our hypothetical aquifers are of large areal extent and differ only in that one is an artesian aquifer, in which water is under pressure, and the other is an unconfined aquifer, in which water-table conditions prevail (that is, the water is under atmospheric pressure only). Assume that each well is pumped at 1,000 gpm for a period of 1 day, during which time the wells receive no replenishment from any source. Under these conditions, the drawdown at the end of the pumping period in observation wells located 300 feet from each of the pumped wells would be about 1 foot in the unconfined, water-table aquifer and about 7 feet in the artesian aquifer. A drawdown of 1 foot, such as would have occurred 300 feet from the well being pumped in the water-table aquifer, would occur about  $1\frac{1}{2}$  miles from the well being pumped in the artesian aquifer.

#### EFFECTS OF INTERBEDDED TILL DEPOSITS

The till-rich zone that generally confines water in the lower aquifer in the Dayton area is an imperfect confining bed. Water will leak through the till as soon as a difference is established between water levels in the upper and lower aquifers. Recharge by leakage into the lower aquifers usually begins soon after pumping starts, slowing the rate of drawdown in this aquifer and eventually stopping it entirely. Observations have shown that recharge from leakage through the confining bed may begin to take effect at any time from a few minutes to several hours after pumping starts in the lower aquifer.

The till-rich zone is absent locally in the Dayton area, and in these areas there is actually only one aquifer and water-table conditions prevail. In other places the till-rich zone consists of discontinuous layers and lenses of till which imperfectly separate the sand and gravel deposits into two aquifers. When wells in the lower aquifer

are pumped in such areas, they may respond initially as though artesian conditions prevailed and then the response changes very quickly to water-table characteristics as flow becomes established between and around the till masses. The effect is the same as though the lower aquifer were ideally artesian and the rate of leakage through the confining bed were very high.

Conditions in the upper aquifer, where water-table conditions generally prevail, also are far from ideal. Because of the horizontal layering of the deposits, and the local presence of interbedded till deposits, the permeability measured parallel to the bedding is generally much higher than the permeability measured normal to the bedding. As a result, the aquifer exhibits artesian properties to some extent, and the water level in a well being pumped responds initially as it would in an artesian aquifer. However, as the cone of influence grows, vertical drainage of the saturated sediments becomes a greater factor in sustaining the yield of the well, and water-table conditions are eventually established.

In a few places in the Dayton area, especially those in which little or no ground water is pumped, the water table in the upper aquifer is within a few feet of the land surface, in the zone of soil and alluvium. The surficial deposits in this zone are relatively impermeable and in places may act as an imperfect confining bed, producing local semiartesian conditions in the upper aquifer.

The recognition of and distinction between artesian and water-table conditions are of major concern to those engaged in pumping-test analysis in the Dayton area. Pumping tests are being used more and more by hydrologists and by some well drillers to determine the characteristics of aquifers, sources of recharge, and yields and proper spacing of wells. However, the difference between artesian and water-table conditions is much less a factor in determining the yield of wells drilled in the valley-fill deposits than are variations in permeability and thickness of the aquifers, choice of well screens, and degree of development of the wells. Moreover, yield is determined to a greater extent by the location of wells relative to sources of recharge than by all the aforementioned factors. Wells screened in the upper aquifer will yield much more water per unit of drawdown if they are close to an infiltrating stream than if they are some distance from the stream, other factors being equal. Wells drilled in the lower aquifer will yield most in areas where the rate of leakage through the confining bed is highest for a given head differential. The ideal place to drill wells in the Dayton area, for largest yields, is as close as practicable to a large infiltrating stream, in an area where the till-rich zone is absent or ineffective as a confining bed and where, as a consequence, there is

virtually one sand and gravel aquifer extending from river level downward to the bedrock surface. A further requirement would be to drill the wells where ground-water levels have not been appreciably lowered by pumping.

#### TRANSMISSION AND STORAGE CHARACTERISTICS

Properties of the valley-fill deposits enabling them to act as a storage reservoir and to transmit water to pumped wells under various hydraulic gradients rank in importance next to the availability of recharge in determining the magnitude of ground-water supplies in the Dayton area. The amount of water taken into or released from storage is important because it usually sets limits on rate of withdrawal between periods of replenishment. The permeability and the saturated thickness of the deposits (the product of these is called the transmissibility) together determine the rates at which water will move in the aquifers under various hydraulic gradients.

The specific yield of an aquifer is the ratio, usually expressed as a percentage, of the volume of water that will drain by gravity from the material to the total volume of the saturated material. For sand and gravel deposits the specific yield commonly ranges from 10 to 25 percent, the exact figure depending partly upon the length of time the sediments are allowed to drain. If a specific yield of 20 percent is assumed for the valley-fill deposits at Dayton, then an estimated  $1\frac{1}{2}$  gallons of water would drain from each cubic foot of the material during dewatering. The valley-fill deposits underlying an area of 1 square mile—roughly the size of Dayton's downtown district—would thus yield from storage nearly 42 million gallons of water if the water table were lowered an average of 1 foot over the entire area. Obviously, a very large quantity of water is in storage in the valley-fill deposits.

A commonly used measure, or coefficient, of permeability is defined as the number of gallons that will flow in 1 day through a 1-foot-square vertical section of an aquifer under a hydraulic gradient of 1 foot per foot; that is, under a vertical drop in water level of 1 foot for each foot of horizontal flow. The coefficient of permeability of a typical clay or till may be 0.1 gpd per sq ft or less, whereas that of a well-sorted sand and gravel may be 2,500 gpd per sq ft or more. As computed from pumping tests, the coefficient of permeability of the sand and gravel deposits in the Dayton area typically ranges between about 1,000 and 3,000 gpd per sq ft. The coefficient of permeability of the till-rich zone in the vicinity of Rohrer's Island ranges between 0.03 and 0.13 gpd per sq ft (Norris, 1959, p. 13).

The rate of flow of ground water is governed not only by the permeability of the aquifer but also by the thickness; the thicker the aquifer, the greater the quantity of water it will transmit in a specified time under a given hydraulic gradient. The product of the coefficient of permeability of an aquifer and the thickness is termed the coefficient of transmissibility and is usually expressed as the number of gallons of water that will flow in 1 day through a 1-foot-wide vertical strip whose height equals the full saturated thickness of the aquifer, under a hydraulic gradient of 1 foot per foot. A sand and gravel deposit whose coefficient of permeability is 2,000 gpd per sq ft and whose saturated thickness is 50 feet would thus have a coefficient of transmissibility of 100,000 gpd per ft (2,000 gpd per sq ft  $\times$  50 ft). The coefficient of transmissibility is a more useful term in describing the water-yielding properties of an aquifer than is the permeability alone. The coefficient of transmissibility of the valley-fill deposits, as determined from pumping tests, ranges from 135,000 gpd per ft for the lower aquifer in the vicinity of Rohrer's Island to about 250,000 gpd per ft for the lower aquifer in the vicinity of the Tait Station of the Dayton Power & Light Co., in south Dayton.

In areas where the till-rich zone is absent, the transmissibility may be as much as 600,000 gpd per ft, although a value this high has not been computed from an aquifer test during this investigation. Such a high value is theoretically possible, however, as a coefficient of permeability of 3,000 gpd per sq ft has been computed for glacial outwash gravels similar to those in the Dayton area. Where such deposits are 200 feet thick, the transmissibility would be 600,000 gpd per ft. A maximum transmissibility of 500,000 gpd per ft for the valley-train deposits in the Dayton area is more likely, however, since these deposits probably do not have a uniform permeability of 3,000 gpd per sq ft through their entire thickness.

#### YIELDS OF WELLS

Typical industrial, commercial, and municipal wells drilled in the valley-fill deposits in the Dayton area range in depth between 60 and 200 feet and yield 100–3,000 gpm. The largest recorded yield is 4,500 gpm, from a 90-foot well (C-29) drilled by the Dayton Water Department on Rohrer's Island. Most of the municipal wells tapping the upper sand and gravel aquifer on and near Rohrer's Island yield 1,500–2,500 gpm from depths of about 65–90 feet. In the same area 10 deeper wells (C-1—C-6, and C-32—C-35) screened in the lower aquifer yield 2,000 gpm each; the total yield of these wells is about 15 mgd.

Typical industrial wells, such as those at the Frigidaire Division plant at Moraine City, yield 600–2,000 gpm and range in depth

To help convey a better understanding of the significance of various coefficients of transmissibility and other measurements used to evaluate the water-yielding properties of aquifers, figures 9-11 are provided. These graphs show the yields of idealized aquifers of three types: those receiving no recharge, those receiving recharge from a line source, and those receiving recharge by leakage through a slightly permeable confining bed.

The drawdown-yield graph (fig. 9) for a 12-inch well shows the theoretical relationship between yield and drawdown in ideal aquifers of various transmissibilities when the well is pumped steadily for 1 day. The drawdowns on the graph are those that would occur if the aquifers were homogeneous and of infinite areal extent, if the water pumped were all from storage, and if the well were 100 percent efficient.

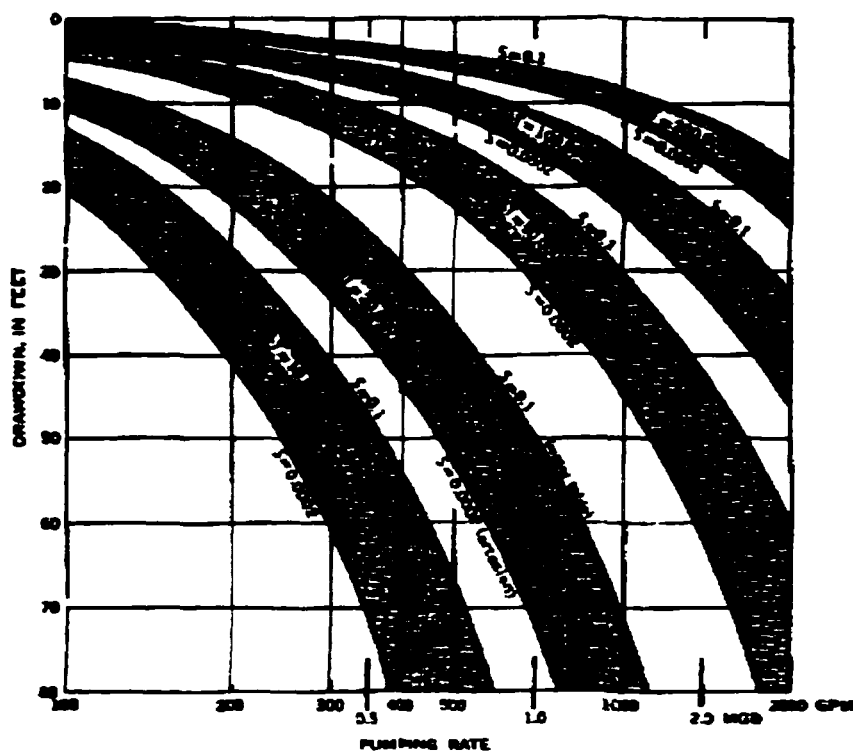


FIGURE 9.—Theoretical relationship between pumping rate and drawdown after 1 day of pumping a 12-inch-diameter well tapping an infinite aquifer receiving no recharge.  $T$ —coefficient of transmissibility, in gallons per day per foot.  $S$ —coefficient of storage.



As the aquifers are assumed to be of infinite extent, no boundary effects are shown.

The graph is intended to convey a general idea of the significance of various coefficients of transmissibility. If it were used to determine the transmissibility of a sand and gravel aquifer from field data or, conversely, as a basis for predicting the drawdown in a well tapping an aquifer whose transmissibility is known, only a very general approximation could be expected. One reason for this is that the efficiencies of wells screened in sand and gravel deposits vary greatly. The drawdown in a poorly developed well may be many times greater, for a given pumping rate, than the drawdown in a properly developed well tapping the same aquifer.

The principal reason, however, why the drawdown-yield graph would give misleading results if used with field data from the Dayton area is that recharge to a well usually becomes effective in a matter of minutes or within a few hours after pumping starts. Recharge slows the rate of drawdown or stops it altogether, and the drawdown after 1 day's pumping is less than it would have been if no recharge had reached the well.

Recharge most commonly is derived from an infiltrating stream if the wells tap the upper aquifer, or it is derived from leakage through the till-rich zone if the wells are drilled into the lower sand and gravel aquifer. The infiltration graph (fig. 10) shows the specific capacities to be expected of wells 12 and 24 inches in diameter drilled at various distances from an infiltrating stream and in aquifers of various transmissibilities. The specific capacity of a well is the ratio of the yield to the drawdown and is usually expressed in gallons per minute per foot of drawdown. Thus a well having a specific capacity of 50 gpm per ft might yield 1,500 gpm with 30 feet of drawdown, or 2,000 gpm with 40 feet of drawdown, or any specified quantity so long as the ratio of the yield to the resulting drawdown is 50 gpm per ft.

Comparison of the infiltration graph (fig. 10) with the drawdown-yield graph (fig. 9) shows no great difference in drawdown for a given pumping rate in a well drawing from storage in an infinite aquifer and in a well receiving recharge from stream infiltration. For example, the drawdown-yield graph shows that after 1 day a drawdown of 8 feet would occur in a 12-inch well pumped at 1,000 gpm and tapping an infinite aquifer whose coefficient of transmissibility is 200,000 gpd per ft. The infiltration graph shows that under similar conditions, except that the well receives recharge from a stream 200 feet away, the specific capacity would be about 188 gpm per ft and hence, at a pumping rate of 1,000 gpm, the drawdown would be about 7.5 feet. In comparing the two graphs, it must be remembered that

the well and the drawdown for various values of the leakage coefficient  $\frac{P'}{m'}$ , where  $P'$  is the coefficient of permeability of the confining bed and  $m'$  is its thickness. If the confining bed through which leakage is occurring has a coefficient of permeability of 0.1 gpd per sq ft and a thickness of 10 feet, its leakage coefficient is  $\frac{0.1 \text{ gpd per sq ft}}{10 \text{ ft}}$ , or 0.01 gpd per cu ft. The graph shows that under the conditions specified, the drawdown in a 24-inch well pumped at 1,000 gpm will be about 4 feet.

The leakage coefficient of the till-rich zone in the vicinity of Rohrer's Island ranges from 0.001 to 0.012 gpd per cu ft, and the coefficient of permeability of the till ranges from 0.03 to 0.13 gpd per sq ft, as determined from a pumping test (Norris, 1959, p. 12). Walton (1960, p. 18) determined that the leakage coefficient for glacial tills and clays at seven places in Illinois ranged from 0.005 to 0.23 gpd per cu ft and that the coefficient of permeability of these beds ranged from 0.03 to 1.6 gpd per sq ft. The range in permeability determined by Walton for six of the seven confining beds in Illinois was from 0.03 to 0.63 gpd per sq ft, the same order of magnitude as that determined for the till-rich zone in the vicinity of Rohrer's Island.

More data on the permeability of glacial till and clay were obtained from laboratory tests of four samples of till and one sample of varved finely laminated clay collected in the Dayton area and analyzed by the U.S. Geological Survey in Denver. The coefficient of permeability of the clay sample, as determined by permeameter methods, was 0.1 gpd per sq ft. For three of the four till samples the coefficient of permeability ranged from 0.01 to 0.5 gpd per sq ft, which compares closely with the range of till permeabilities determined at Rohrer's Island and in Illinois. The coefficient of permeability determined for the other till sample from the Dayton area was very high and is believed to be in error.

According to the evidence, a typical coefficient of permeability of glacial till is about 0.1 gpd per sq ft. If such a till is 25 feet thick and confines water in an underlying aquifer, the leakage coefficient of the confining bed =  $\frac{0.1 \text{ gpd per sq ft}}{25 \text{ ft}} = 0.004 \text{ gpd per cu ft}$ . Thus, as indicated by the "leaky-aquifer" graph (by interpolation), the theoretical drawdown in a 24-inch well pumping 1,000 gpm from an underlying artesian aquifer whose coefficient of transmissibility is 200,000 gpd per ft is about 6 feet. Such a well would have a specific capacity of about 160 gpm per ft, corresponding to that of a similar well in a water-table aquifer of the same coefficient of transmissibility located

about 100 feet from an infiltrating stream. (See infiltration graph, fig. 10.)

#### CONSTRUCTION AND DEVELOPMENT OF WELLS

The construction and development of wells in the Dayton area have evolved in recent years into fairly standard methods and procedures. Typically, when wells are drilled for a factory, the choice of the drilling site is restricted by the property lines to a plot of perhaps an acre or less. The well site is selected by the plant engineer, who is guided by the general layout of the plant, the location of any existing wells, and the accessibility to existing power-distribution lines. Test holes are usually, though not always, drilled at the chosen site before the production well is put down. Results of the test drilling, together with records of existing wells, may dictate a different site for the production well.

Proposed well sites are usually rejected if the aquifer contains excessive amounts of silt or clay, or if layers or masses of till are present that locally replace the permeable sand and gravel. In a very few instances, the results of test drilling have been so discouraging to drillers and plant officials that no attempts were made to drill supply wells. Where the plant grounds cover a relatively large area, say 10-20 acres, several test holes may be put down for each production well drilled. Usually, the test holes are drilled by cable-tool or percussion-type equipment, similar to that used in drilling the production wells. In recent years use of rotary equipment has become more common and is generally acknowledged to give better results in test-hole drilling than does percussion-type equipment. One driller uses a mechanical separator during drilling to remove the sand and gravel particles from the drilling mud for inspection, and he logs the hole by means of a portable electric logger, which makes gamma-ray, resistivity, and self-potential logs of the formations. Use of these geophysical tools usually gives a far better picture of geologic conditions at the site than can be obtained from drillers' logs alone.

When the production well has been drilled to the selected depth, a brass or bronze well screen is lowered to the bottom of the casing (fig. 12) and the casing is then pulled back, exposing the screen to the sand and gravel aquifer. The diameter of a typical production well is governed by the anticipated yield of the well; if the expected yield is large, the casing diameter also will be made relatively large, so as to accommodate the required pump. Wells yielding 100-300 gpm commonly are 6-8 inches in diameter; wells yielding 300-500 gpm are 8-10 inches in diameter; wells yielding 500-1,000 gpm may be 10-12 inches in diameter; and those yielding 1,000-3,000 gpm are 16-20 inches, or more, in diameter.



FIGURE 12.—Installation of a well screen at the Frigidaire Division plant at Moraine City. After screen is in place, casing will be pulled back to expose the screen to the sand and gravel aquifer.

Theoretically, increasing the diameter of a well does not increase its yield proportionately, and calculations show that under water-table conditions the yield of a 24-inch well is only 15–30 percent greater than the yield of a 3-inch well. In practice, however, well diameter usually has a very significant effect on the yield owing to comparatively large head losses through small-diameter well screens. In comparing the yields of 12- and 18-inch wells screened in sand and gravel deposits at Louisville, Ky., Borabaugh (1933, p. 11) stated that for relatively low discharge rates the specific capacities of the wells differed by less than 5 percent, but for comparatively high rates they differed by more than 20 percent.

In the Dayton area there is a fairly close correlation between the diameters of wells and their specific capacities, according to pumping-

test data from approximately 150 wells. Most of these data are from drillers' acceptance tests, usually lasting 2-3 hours. Commonly such a test is ended when the water level in the well approximately stabilizes or "levels off," as determined by periodic measurements made with a steel tape or an air-line gage. Of the wells studied, 27 were less than 12 inches in diameter, and all but 3 of these had specific capacities of less than 50 gpm per ft. The rest of the wells studied were 12 inches in diameter, or larger; 65 percent of these larger wells had specific capacities greater than 50 gpm per ft.

Although the greater screen-intake area resulting from the increased well diameter is probably the major cause of the higher specific capacities of the larger wells, it may not be the only factor. When wells are pumped at relatively high rates, recharge effects occur more quickly than when the same wells are pumped at lower rates. During short periods of pumping, as in typical acceptance tests of wells, this fact becomes important. A well pumped at a relatively low rate may draw water entirely from storage in the aquifer during a pumping test of a few hours' duration, whereas the cone of depression formed around the same well when it is pumped at a higher rate is larger and may reach a source of recharge long before the test is over. Recharge slows or stops the drawdown, and the computed specific capacity of the well is therefore much greater at the higher pumping rate.

Modern pumps in the Dayton area are almost all the deep-well turbine type. In the turbine pump an electric motor, mounted on the casing and coupled to a long shaft, turns a series of impellers housed in the lower end of a vertical column suspended in the well below the water level. Water enters the column at the impellers, is forced upward, and is discharged through an orifice in the pump base. The discharge is governed principally by the number of impellers, called stages, used in the pump. These can be added or removed as the occasion demands. The design of the deep-well turbine pump eliminates the need for costly shelters or pumphouses, and most such pumps are placed in the open where they are readily accessible for servicing or maintenance (fig. 13).

The deep-well turbine pump has been in common use for about 30 years. Before its advent, displacement or cylinder-type pumps, centrifugal pumps, and a few air-lift pumps were used, and some of these types are still in service in the Dayton area. The jet or ejector-type pumps, in common use on rural and domestic wells, are seldom used in industrial wells because of their small capacity.

The first step in the development of an industrial well in the Dayton area is selection of the proper screen. Thirty or forty years ago screens were considered primarily as strainers whose function

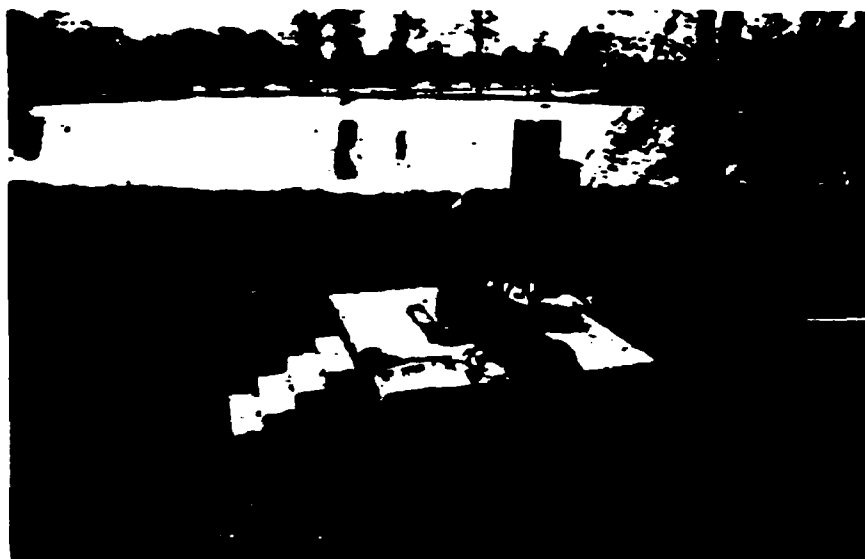


FIGURE 18.—High-capacity turbine pump installed on municipal well at Bohrer's Island. Recharge pond in background. Photograph courtesy of the Dayton Daily News.

was to exclude from the well everything but the water. Consequently, the slots or openings in the screens were made small enough to keep out sand and other fine particles. This concept has changed, however: modern well screens are designed so that the openings are large enough to pass 40–60 percent of the aquifer materials. The size of the screen openings used in a typical production well is usually determined from a sieve analysis of sand and gravel samples collected in drilling the test hole. During development the finer grained material is washed through the screen and is removed from the well by pumping or bailing. This forms what is termed a natural “gravel pack” around the well screen and usually results in a much more efficient well than that obtained by earlier construction methods.

Artificial gravel packs also are used in some wells. These are constructed by first putting down a large-diameter casing, into which is inserted a casing of smaller diameter having a screen at its lower end. The annular space between the large-diameter casing and the well screen is filled with gravel of predetermined size and the outer casing then is withdrawn, exposing the gravel packing.

A few well screens in the Dayton area are of cemented gravel construction, in which graded gravel is mixed with cement and cast into a porous thick-walled screen reinforced by wire mesh and longitudinal

iron rods. The size of the gravel used in these screens is determined by analysis of samples of sand and gravel from the aquifer.

A few industrial wells in the Dayton area are not screened at all, except through perforations in the well casing. Most of these wells were drilled during World War II, when metal screens were scarce. Some, though not all, are of low efficiency or short life. A well driller informed the authors that he was replacing several wells, 12 years old, in which perforated casing was used in place of screens.

The yield of a well is roughly proportional to the length of the well screen, as the more fully a well penetrates an aquifer the smaller are the losses due to "partial penetration," which occur even in a perfectly homogeneous aquifer. (See Peterson and others, 1953.) In the sand and gravel aquifers at Dayton, horizontal layering of the deposits causes the permeability transverse to the bedding to be much less than the permeability parallel to the bedding. In some areas thin layers of clay or till interbedded with an otherwise homogeneous-appearing sand and gravel aquifer may further reduce the permeability in the vertical direction. Those factors greatly increase losses in wells that only partly penetrate the aquifers. The obvious solution to this problem is to use a long screen, which can "tie together" the more permeable parts of the aquifer. Moreover, the longer the well screen, the greater is the total area of the screen openings and the smaller is the head loss as the water flows through the screen into the well.

The screen lengths of about 60 wells in the Dayton area were plotted against their specific capacities. Wells whose screens were up to 10 feet in length had specific capacities up to 40 gpm per ft.; wells whose screens were 10-20 feet in length had specific capacities up to 160 gpm per ft.; and wells whose screens were 20-30 feet in length had specific capacities up to 320 gpm per ft. These are maximum or near-maximum capacities for the respective screen lengths. Some wells studied, whose screens were 20-30 feet long, had lower specific capacities than wells having 10-foot screens.

After a well is drilled and the screen is installed, the well is developed to permit water to flow more freely through the sand and gravel in the immediate vicinity of the well screen and thus to enter the well with minimum head loss. Development consists of removing part of the finer grained material from the aquifer; this causes rearrangement of the sand and gravel particles adjacent to the well screen. Removal of the finer particles from the sand and gravel envelope surrounding the screen reduces the chance that the well will "sand up" or "pump sand" when the pump is installed. The foregoing terms are commonly applied to the fouling of the pump or distribution lines by fine sand pumped up with the water.

Sometimes wells are developed by introducing compressed air into the water through a long hose or pipe. This agitates and lifts the water until, laden with sand and other particles washed through the well screen, it overflows from the casing.

The most common method of developing wells in the Dayton area is by surging. In this method a tightly fitting surge block affixed to the drilling tool is worked up and down in the well like a ramrod in a gun. This forces water back and forth through the well screen at comparatively high velocity and brings the finer material into the well where it can be removed by bailing. Thorough development may require 1-2 days or even longer and is usually worth the expense on the basis of pumping costs alone. The difference in drawdown between wells that are properly developed and wells that aren't is commonly as much as 10 feet. For a pumping rate of 1,500 gpm, the cost of operating an improperly developed well may be as much as \$1 per day more than for operating a properly developed well. After a few years the additional pumping cost could equal the original cost of the well. Moreover, added maintenance problems usually are associated with inadequate well development.

Some wells decline in efficiency after a few years and may require redevelopment at intervals. Several conditions may cause this decline. The most common is an incrustation of the well screen caused by either the deposition of tiny materials in the screen openings and in the sand and gravel adjacent to the screen or by the growth of iron- or sulfate-forming bacteria in a slimy deposit, which clogs the well screen or the gravel around the well.

Iron-forming bacteria of the genus *Crenothrix* may grow in water containing iron in excess of about 0.2 parts per million. Methods of control include disinfection and regular treatment of the well and pumping equipment with hydrochloric acid or other chlorine compounds. Where contamination extends into the aquifer, some distance away from the well face, it is difficult to control and may eventually threaten an entire well field. Contamination of an aquifer over a large area is not known to occur anywhere in the Dayton area, though the problem locally is acute and should be carefully watched so that widespread control measures can be taken quickly if necessary.

Serious problems of well maintenance caused by iron-forming bacteria have occurred at the National Cash Register Co. plant and at the plants of the Delco-Moraine and Frigidaire Divisions of General Motors Corp. At the National Cash Register Co. plant a well drilled in 1950 was treated with acid in 1954 and again in 1958 in efforts to restore its efficiency, which had been appreciably reduced by the growth of iron-forming bacteria. At the Delco-Moraine Division



plant, a well (No. 338) drilled in 1948 to a depth of about 125 feet soon declined in yield and was deepened in 1950 to 200 feet. Since 1950 the well has twice been clogged by bacterial growth and both times was treated with acid. It has now been abandoned. No doubt the yield of many other wells in the Dayton area has been adversely affected by iron-forming bacteria. The problem warrants a more systematic study than was possible during this investigation.

#### CONTROLLED PUMPING TESTS

The method most commonly used to determine the storage and transmission properties of an aquifer is based on the nonequilibrium formula, which was introduced by Theis (1935). In this method the effects of pumping a well at a known constant rate are measured at several observation wells that tap the same aquifer. Graphs of drawdown versus distance from the pumped well, or of drawdown versus time since pumping started, are used to solve equations that express the relation between the coefficients of transmissibility and of storage of an aquifer and the lowering of water levels in the vicinity of a pumped well (Brown, 1953).

By methods based on the theory of images (Ferris, 1948), boundary effects are evaluated whereby the position, with respect to a pumped well, of a source of recharge (such as an infiltrating stream) or of an impermeable barrier (such as bedrock valley walls) can be determined. Effects of leakage through a semiconfining layer, such as a bed of glacial till, may be determined by methods described by Hantush (1955). Examples of pumping-test analysis were presented by Walton (1953, 1960) and by Norris (1959).

Control of pumping tests is made difficult in the Dayton area by interference from other wells and by the scarcity of observation wells. Technical difficulties hamper maintenance of constant pumping rates and precise measurement of ground-water levels in observation wells. Close control of a pumping test for periods longer than a few hours usually is not possible in the Dayton area. This difficulty, plus the heterogeneity of the aquifer, complicates interpretation of the test results.

One of the most difficult problems of interpretation is that of determining whether recharge to a well comes directly from an infiltrating stream or from vertical leakage through a till bed. The effects on ground-water levels observed during typical pumping tests are much the same for either source of recharge. Seldom are there enough properly spaced observation wells to indicate unequivocally the source of recharge; consequently, a great deal of judgment based principally upon a knowledge of the geology is involved in the analysis.

Serious error might result in attempting to predict the long-term yield of wells if the source of recharge was mistakenly identified as an infiltrating stream, whereas the actual source was vertical leakage through a confining bed of low permeability. Under the mistakenly identified condition, the growth of the cone of depression, ideally, would be halted by the infiltrating stream and recharge would be maintained at a relatively constant rate as long as flow occurred in the stream. Under the actual condition, recharge would be from storage in the leaking bed. If replenishment to that bed were deficient, as perhaps it might be in periods of drought, the recharge to the underlying aquifer also would diminish, perhaps in critical amounts.

The problem of interpretation is compounded when recharge to a pumped well is principally from water that flows from the upper to the lower aquifer through openings in the till-rich zone. Under such conditions the growth of the cone of depression is halted by a change in the aquifer from artesian to water-table conditions, and the effects on drawdown are similar to those caused by recharge from an infiltrating stream or by vertical leakage through a poorly permeable bed. An opening in the till-rich zone can be located by image-well methods if enough observation-well data are available, but the rate of recharge through the opening cannot be evaluated by ordinary field techniques.

Further complications arise where several openings occur in the till-rich zone as, for example, in an area where the till is in the form of closely spaced lenses or masses. Under these conditions it may be a practical necessity to consider that recharge originated as leakage through a confining bed having a relatively high leakage coefficient, because the amount of data required to define the hydraulic system more completely would be so great as to render unlikely its collection in the field. Unfortunately, a leakage coefficient approximated in this way can be applied only with caution, and only with respect to the pumped well. It would have a different value for almost any other well in the area whose location differed with respect to the individual openings in the till-rich zone.

Although pumping-test data are useful in determining initial pumping rate, well efficiency, and short-term drawdown in a pumped well, seldom do they constitute an adequate basis for predicting the yield of large ground-water systems. The perennial yield of an aquifer is determined not so much by its hydraulic properties as by the average annual recharge, just as for a surface-water reservoir.

Several of the better controlled and instrumented pumping tests made in the Dayton area are the basis for the computed values of the principal hydraulic properties—the coefficients of transmissibility and

permeability and the leakage factor—used in this report. These pumping tests are briefly described below, and the computed values of the hydraulic properties are listed in table 2. The analytical procedures are not described, and the water-level data are omitted. A pumping test made in 1953 by the U.S. Geological Survey at the Dayton municipal well field at Rohrer's Island has been more exhaustively treated and is the subject of another publication (Norris, 1959). The interpretive procedures described in that report are generally similar to those used in analysis of the other tests in the Dayton area. The hydrologic coefficient given in the description of the pumping tests are the authors' unless otherwise stated.

The permeability of the lower sand and gravel aquifer is uniformly high in the Dayton area, except locally in the downtown district, where several large valley glaciers coalesced. As a consequence, the till-rich zone is unusually thick, and the sand and gravel deposits contain relatively large quantities of fine sand and silt, which reduce their permeability.

TABLE 2.—Hydrologic coefficients obtained from pumping tests of wells in lower aquifer

Test site	Date of test	Transmissibility of aquifer (gpd per ft)	Permeability (gpd per sq ft)	Confining bed	
				Leakage (gpd per cu ft)	Vertical permeability (gpd per sq ft)
Rohrer's Island area	October 1955	215,000	2,500	0.001-0.012	0.03-0.13
Miami valley near Beard-stown Rd.	April 1960		2,300		
Frickdale Div. plant No. 1, Taylor St.	February 1961	41,000	1,000		
Tank Sta., Dayton Power & Light Co.	April 1960	* 200,000-280,000	* 2,000		
Montgomery County Sanitary Dept., Laraine Rd. well field	April, June 1950		* 2,000-2,500		
Montgomery County Sanitary Dept., Dryden Rd. well field	April 1955	240,000	1,500		

\* Estimated.

#### PUMPING TEST AT ROHRER'S ISLAND

A test conducted in 1953 by the U.S. Geological Survey at the Rohrer's Island well field of the city of Dayton was described by Norris (1959). The test was made in wells drilled in the lower aquifer, which is about 50 feet thick and is separated from the upper aquifer by 11-50 feet of till. At the test site the coefficient of permeability of the sand and gravel is 2,500 gpd per sq ft, and the coefficient of transmissibility of the lower aquifer is 125,000 gpd per ft. The permeability of the till confining bed ranges from 0.03 to 0.13 gpd per sq ft, on the basis of data from five observation wells, and the leakage coefficient of the

confining bed ranges from 0.001 to 0.013 gpd per cu ft. A median value of the leakage coefficient, 0.003 gpd per cu ft, was selected as generally representative of the well field. This value was checked by relating it to the quantity of water subsequently pumped at the well field, the observed drawdown in wells, and the areal extent of the cone of depression as estimated from the geologic data. Good agreement was obtained between the observed facts and the theoretical calculations which were based on the selected value of the leakage coefficient. Although this value probably cannot be applied elsewhere in the Dayton area, the range of permeability of the till may be useful in making approximations of well yield where the till is extensive and its thickness is known.

#### PUMPING TEST AT MIAMI RIVER WELL FIELD

Schaefer and Walton, consulting hydrologists, made a pumping test in April 1956 at the Miami River well field, in which well T-2 was pumped about 4 days at a rate of 1,200 gpm. The pumped well was screened in two places, at depths of 68-78 feet and 88-108 feet, and was open both above and below an 8-foot-thick till deposit, which evidently constitutes the hydraulically most effective part of the till-rich zone at the test site.

During the test the pumped well received recharge almost immediately from the upper aquifer. Schaefer and Walton noted in their report to water-department officials (written commun., 1956) that the water level in an observation well 19 feet deep located 80 feet from the pumped well "responded to the withdrawal of water 15 seconds after the pump was turned on or off." According to Schaefer and Walton, "water in the shallow aquifer was also confined under slight artesian pressure because the water table was above the base of the semiconfining alluvial materials." This would account for the very rapid response to pumping effects in the upper aquifer.

Schaefer and Walton determined the coefficient of permeability of the sand and gravel deposits at the test site to be approximately 2,300 gpd per sq ft. They stated (written commun., 1956):

Recharge to the deeper materials, at least in the vicinity of the test site, will occur as leakage of water through the semiconfining bed. Relatively deep cones of depression will have to be created to induce large quantities of water to leak through the clayey materials. The effectiveness of artificially recharging the deeper sand and gravel by spreading water over the shallow deposits will be decreased by the presence of the relatively impermeable bed.

#### PUMPING TEST AT FRIGIDAIRE DIVISION PLANT NO. 1 AT TAYLOR STREET

In February 1951 the U.S. Geological Survey made tests in two 12-inch wells screened in the lower aquifer at the Frigidaire Division

plant No. 1 in downtown Dayton. The till-rich zone, 80-90 feet thick, is thicker at the test site than at most other places in the Dayton area (pl. 3), and the upper and lower aquifers are correspondingly thin, each about 40 feet thick.

During the test, well 38, which is 181 feet deep and screened in the lower 20 feet, was pumped at a rate of approximately 500 gpm for 8 hours. Drawdown and recovery measurements were made in well 87, which is 193 feet deep and 130 feet distant from the pumped well.

Well-interference effects, caused by operation of wells at other downtown business places, were noted during the test, and only water-level data obtained during the first 2 hours of the drawdown and recovery periods were used in the test analysis. The computed coefficient of transmissibility was approximately 40,000 gpd per ft, and the coefficient of permeability was about 1,000 gpd per sq ft, less than half the value computed for the lower aquifer at Rohrer's Island. The leakage coefficient could not be determined from the Frigidaire site test data, as recharge did not become effective during the first 2 hours of pumping.

The 1,000 gpd per sq ft coefficient of permeability calculated from the test of the Frigidaire Division wells may be lower than the true permeability of the lower aquifer at this site. A discrepancy may have resulted from distortion of the field data by noncontrolled pumping in nearby wells. However, the calculated value, which is based on data from the observation well, checks closely with that based on the actual drawdown observed in the pumped well during the test. The drillers' logs of wells 37 and 38 report "dirty gravel" at several places in the stratigraphic sequence. This may indicate that the aquifer material is not well sorted at this site and that it contains a high proportion of silt and clay, which would reduce its permeability. The computed permeability coefficient, 1,000 gpd per sq ft, probably is not representative of the permeability coefficient in the downtown area.

#### PUMPING TESTS AT DAYTON POWER & LIGHT CO., FRANK M. TAIT STATION

In April 1956 a pumping test was made at the Tait Station, of the Dayton Power & Light Co. by a board of consultants, assisted by Mr. Robert E. Reemelin of the Miami Conservancy District. Well 524, which is 155 feet deep and screened in the lower 50 feet, was pumped for about 6 hours at a rate of 3,050 gpm. The pumped well is 195 feet from the Miami River, on the east bank of the stream. Drawdown and recovery measurements were made in wells 531 and 530, respectively, 695 and 790 feet southeast of the pumped well, in a direction away from the river.

The specific capacity of the pumped well was approximately 110 gpm per ft, which suggests a coefficient of transmissibility in the range

of 200,000-250,000 gpd per ft and indicates a coefficient of permeability for the lower aquifer of about 2,000 gpd per sq ft.

The test data are partly anomalous, probably because of the inhomogeneity of the aquifer and possibly because of interference of nearby wells; therefore, they are not amenable to the rigorous methods of analysis based on commonly used equations of ground-water flow. Recharge effects were noted in the observation wells about 10 minutes after pumping started, but whether this recharge originated at the Miami River or resulted from vertical leakage through the till-rich zone could not be determined. Recharge from both sources probably influenced water levels during the test.

**PUMPING TESTS AT THE LAMME ROAD WELL FIELD OF THE MONTGOMERY COUNTY SANITARY DEPARTMENT**

Two pumping tests were made at the Lamme Road well field in 1950, when development of the field was begun. In April the Ralph L. Woolpert Co. pumped well M-4, which is 166 feet deep and screened in the lower 28 feet for 24 hours at the rate of 1,000 gpm. Drawdown measurements were made in wells M-1 and M-2, respectively 258 and 380 feet from the pumped well. Data from the test were furnished to the authors by Mr. John Eachiman of the Woolpert Co.

In June 1950, the U.S. Geological Survey pumped well M-3, which is 187 feet deep and screened in the lower 30 feet, for 24 hours at the rate of 1,000 gpm. Drawdown measurements were made in well M-4, which is 272 feet distant from the pumped well.

Results of the pumping tests indicate a relatively high coefficient of transmissibility for the lower aquifer and a coefficient of permeability of 2,000-2,500 gpd per sq ft. Stabilization of water levels occurred very rapidly during each of the tests, and there was almost no further drawdown in the wells after about 5 minutes of pumping. Distortion of the flow field, caused by a clay lens that lies just above the depth at which most wells are screened, precluded more rigorous analysis of the test data.

The effect of this clay lens in retarding the vertical movement of water is shown by the results of redeveloping well M-6 and installing a longer screen in it. When placed in service this well was screened between depths of 127 and 187 feet, immediately below the clay lens, and it had a specific capacity of about 40 gpm per ft. The specific capacity declined in about 1½ years to 18 gpm per ft. The well was redeveloped and an additional 15 feet of screen was installed between depths of 76 and 91 feet, immediately above the clay lens. After this was done, the specific capacity of the well was 113 gpm per ft, nearly three times the original capacity.

**PUMPING TEST AT DRYDEN ROAD WELL FIELD OF THE MONTGOMERY COUNTY  
SANITARY DEPARTMENT**

In April 1955, the U.S. Geological Survey made a pumping test of well M-10, which was pumped at the rate of 380 gpm for about 24 hours. Drawdown and recovery of the water level were measured in well M-12, which is 273 feet from the pumped well. Results of the tests indicate a coefficient of transmissibility for the lower aquifer of about 240,000 gpd per ft and a coefficient of permeability of about 1,600 gpd per ft. The aquifer is highly artesian, and recharge effects were noted in the observation well approximately 1 minute after pumping started in well M-10.

**HYDROLOGY OF THE VALLEY-FILL DEPOSITS****GROUND WATER IN STORAGE**

The availability of ground water in the Dayton area depends in part upon the quantity of water in storage in the valley-fill deposits, even though this quantity cannot be entirely withdrawn through wells. The sand and gravel filled valleys, a major element of Dayton's physical geography, constitute a large natural reservoir which matches in capacity some of the world's largest manmade lakes. The total area underlain by sand and gravel in the Miami Valley between Holes Creek, south of the city, and Needmore Road, near the north boundary, together with the segment of the Mad River valley extending from its mouth to Huffman Dam, and including smaller areas near the mouths of the Stillwater River and Wolf Creek, is approximately 40 square miles. From this area is pumped all but a tiny fraction of the ground water used for industrial and municipal purposes at Dayton.

If the sand and gravel deposits in this area of 40 square miles average 200 feet in thickness, their total volume is about  $1\frac{1}{2}$  cubic miles, or about 15 times the volume of material excavated during construction of the Panama Canal. If the sand and gravel is uniformly saturated below the depth of, say, 30 feet and if the porosity of these deposits averages 30 percent, the total quantity of water in storage in the area under consideration is about 425 billion gallons. This enormous quantity of water, if it could all be extracted from the ground, would supply Dayton's water requirements for 10 years at present pumping rates. In the table that follows, the storage capacity of the valley-fill deposits can be compared with that of several manmade surface reservoirs.

Reservoir	Capacity, in million gallons
Lake Mead.....	2,670
Valley-train deposits at Dayton.....	425
5 retarding basins of the Miami Conservancy District (total).....	273
Hoover Reservoir (Columbus, Ohio).....	19

The natural underground storage at Dayton is comparable to that provided by very large artificial reservoirs costing many millions of dollars. According to estimates made by a board of consultants, the cost of constructing proposed reservoirs at Covington and DeGraff and on Beaver and Elk Creeks would average \$135 per acre-foot of capacity. On this basis, a surface-water reservoir having the storage capacity of the valley-fill deposits in the Dayton area would cost about \$175 million to construct.

To carry such comparison further, the underground reservoir at Dayton requires no maintenance, it is not readily subject to silting or pollution, and it yields water of good chemical and bacteriological quality and of generally low and uniform temperature. Moreover, the valuable land underlain by this natural reservoir is not taken out of use, as it would be if it held a surface reservoir, nor does the water have to be piped to most points where it is used, as is true of surface-water supplies.

The rate at which water can be withdrawn from the valley-train aquifers, as computed from pumping tests and as demonstrated by the high yields of wells, exceeds Dayton's presently foreseeable need for water. However, the amount that can be withdrawn on a perennial basis is not determined so much by the hydraulic properties of the aquifer as by the average annual recharge.

#### RECHARGE

Recharge to the valley-fill deposits has its origin principally in that portion of the precipitation which runs off or seeps into the streams above Dayton and enters the aquifers in the Dayton area by infiltration through streambeds. The water enters the ground where the water table in the deposits underlying the stream has been sufficiently lowered by pumping to reverse its natural slope. This is the process, called induced infiltration, by which all large ground-water developments in the Dayton area are chiefly replenished. In a sense, the valley-fill deposits function as vast natural filter beds into which water is drawn from the streams and purified before use.

A minor amount of recharge to the aquifers in the Dayton area is derived from precipitation which falls on the valley-fill deposits and



infiltrates directly to the water table in the vicinity of pumped wells. The inflow of ground water from the uplands is a major factor locally, especially where the uplands consist of thick permeable deposits. The conditions are present south of Dayton in an area of 5 square miles on the east side of the Miami River valley between Southern Hills and the vicinity of Holes Creek, where kame deposits of sand and gravel form high hills and rugged terrain and there is no well-developed surface drainage. Much of the precipitation in this area enters the ground and flows into the valley-fill deposits as ground water, some of which may briefly emerge as springs before reentering the ground farther down the valley slope.

Ground-water runoff intercepted by pumping wells may be highly valuable to individual water users whose wells are comparatively far from infiltrating streams, near the sides of the valleys. For example, the Montgomery County Sanitary Department wells at Lamme Road receive some recharge from the sand and gravel deposits on the adjacent upland. Similarly, wells at the Focke Packing Co., plant on the south side of the Mad River valley near Eastwood Park are replenished in part by ground water moving toward the Mad River from the sand and gravel deposits on the hill behind the plant.

Recharge to the ground-water reservoirs varies seasonally and, in the Dayton area, occurs principally between late fall and early spring. Beginning in late October or early November and continuing through the winter and spring until the following April or May, ground-water levels generally rise. During the rest of the year they usually decline; however, rising trends as well as long-term declines in ground-water levels are often interrupted and temporarily reversed by droughts or floods, or by changes in pumping practices.

The hydrographs of wells Mt-2, Mt-3, and Mt-6 (pl. 2) show the fluctuations of ground-water levels, based on plottings of the lowest weekly water levels recorded in the wells. Wells Mt-2 and Mt-6 are in downtown Dayton, at the Fourth Street Station of the Dayton Power & Light Co. and in the basement of the Municipal Building at Second and Ludlow Streets, respectively. Well Mt-3 is south of downtown Dayton at the intersection of Stewart Street and Patterson Boulevard, opposite the National Cash Register Co. plant. The number of times that peak water levels occurred and that annual recharge began in specific months are shown for most of the period of record in the table that follows.

Well	Period of record	Number of times—A: Peak value reached; B: Annual recharge began	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20-2	1949-51	A----- B-----	1	2	4	7	1	2						
20-3	1949-51	A----- B-----	1	2	1	4	2	1	1	3	5	4	1	1
20-4	1949-51	A----- B-----	1	4	3	4	1	1			1	3	6	4
20-5	1949-51	A----- B-----								4	7	2		

The total amount of recharge derived from local precipitation, including that part directly received by the valley-fill deposits, as well as that part entering the aquifers as ground-water flow from the adjacent uplands, amounts to about one-fourth of Dayton's present water use. Partly on the basis of calculations made by Walton and Scudder (1960, p. 35) in the Fairborn area, a little less than one-third of the precipitation received on the valley floor is estimated to infiltrate to the water table in areas outside the city. This amounts to about 12 inches per year, or approximately 15 mgd. Locally, recharge from direct precipitation probably differs greatly from the estimated annual rate, but data from which these rates can be calculated are not available.

Inflow of water to the valley-fill deposits from the adjacent uplands, including both surface runoff that infiltrates to the water table after it reaches the valley floors and ground-water inflow, is estimated to average about 10 mgd in the principal areas of pumpage. This rate, too, is subject to much local variation. Little surface runoff can reach the valley-fill deposits in paved areas of the city, and little subsurface flow occurs from the upland areas on both the east and west sides of Dayton, which are generally underlain by relatively impermeable Ordovician shale covered by a thin blanket of glacial till. In those areas ground-water inflow may amount to no more than about 0.1 mgd per mile of valley wall, about the same as the rate determined by Walton and Scudder (1960, p. 34) in the Fairborn area. However, ground-water inflow from the sand and gravel deposits that compose the upland on the east side of the Miami River valley between Dayton and Holes Creek is estimated at more than 1 mgd per mile of valley wall, or a total average inflow in that area of about 5 mgd.

Although recharge from local precipitation accounts for the replenishment of approximately one-fourth of the ground water presently pumped in the Dayton area, it cannot be increased appreciably, whereas recharge from the induced infiltration of streamflow, which sustains most of Dayton's pumpage, will increase as ground-water

development grows. Moreover, there are ways to increase the rate of stream infiltration artificially. For example, at the municipal well field at Rohrer's Island infiltration takes place through the beds of artificial channels and lagoons, which are dredged periodically to maintain a rate of infiltration much higher than that which occurs naturally in the Dayton area.

#### CHARACTERISTICS OF STREAMFLOW

The most important hydrologic factor at Dayton, relative to water supply, is the regimen of flow in the Miami River and its principal tributaries. Significant flow characteristics of streams in the Dayton area were discussed by Cross and Hedges (1959, p. 139, 141, 144, 145, and 146) and are listed in table 3.

The flow that is equaled or exceeded 90 percent of the time is near the minimum flow recorded in most Ohio streams and is generally considered to come primarily from the discharge of ground water. The amount of ground-water discharge depends largely upon the natural storage properties of the formations within a drainage basin. Cross (in Norris and others, 1948, p. 64) stated:

A river flowing from a basin of bare, impermeable rock would experience a flood following every substantial rain, and would carry little or no flow a few hours later. Another river with the same mean flow, but flowing over an area of thick, permeable sands and gravels, might have but a slight increase in flow after a rain, and high sustained flows between rains. Natural lakes and artificial reservoirs would have the same effect, but in the Miami River basin the storage is for the most part in the glacial deposits, and is ground-water storage.

For comparative purposes the flows equaled or exceeded 90 percent of the time are related to the areas of the respective drainage basins, and this ratio, usually expressed in cubic feet per second per square mile, is termed the dry-weather-flow index. The Mad River's dry-weather-flow index, 0.293 cfs per sq mi, is the highest in Ohio; it reflects the large amount of natural storage in the sand and gravel deposits in the drainage basin.

The mean flow of the Miami River at Dayton, 1,422 mgd, represents about 18 times as much water as is now being pumped in the area, and the flow equaled or exceeded 90 percent of the time 191 mgd, is more than  $1\frac{1}{2}$  times the present water use. However, neither of these figures is very meaningful as they reveal little about other significant characteristics of streamflow, especially the discharge available in extended periods of drought. Data on drought frequency or dry-weather flow are commonly used in surface-water studies to compute the size of proposed storage reservoirs so that a minimum flow of some selected magnitude will be obtained or, conversely, to calculate the yield

TABLE 2.—Characteristics of flow of the principal streams in the Dayton area, Ohio

Stream	Drainage area above Dayton (sq mi)	Station location	Mean flow		Flow equaled or exceeded 50 percent of the time		7-day discharge (cfs per sq mi)	Maximum daily discharge		Minimum daily discharge		Remarks
			cfs	mgd	cfs	mgd		cfs	mgd	cfs	mgd	
Miami River	2,618	1,200 ft downstream from Main Street Bridge in Dayton; 14 miles downstream from Mad River.	2,200	1,423	200	104	8.140	60,000	20,000	100	70	Flood flow regulated at 4 retarding basins above station. Water is diverted above station by embankment in vicinity of Beardstown Rd. (Miami River) and Beaver's Island (Mad River) far into Dayton; most return flow from diversions by sump station in Dayton river system.
Mad River near Dayton.	600	600 ft downstream from Stillman Dam; 9 miles northeast of Dayton.	600	600	150	100	800	17,000	11,220	04	01	Flood flow regulated by Stillman retarding basin (107,000 acre-ft).
Stillwater River at Englewood.	648 (above Englewood).	1,000 ft downstream from Englewood Dam; 0.5 miles upstream from mouth.	570	200	20.0	20	.001	8,910	6,000	4.0	2.1	Flood flow regulated by Englewood retarding basin (312,000 acre-ft).
Wolf Creek at Dayton.	60.6	At West River view Avenue Bridge in Dayton; 1.5 miles upstream from mouth.	60.6	26.0	2.6	2.3	.002	2,000	1,000	1.1	.0	
Miami River at Taylorville.	1,160	600 ft downstream from Taylorville Dam; 0.5 miles upstream from Stillwater River.	601	604	61.0	60.9	.070	24,000	16,000	20	20	Flow regulated at retarding basin on Miami River just above station (100,000 acre-ft, 1.160 sq mi) and on Lanesville Creek at Lanesville (70,000 acre-ft, 201 sq mi). Low flow regulated by Indian Lake (44,000 acre-ft, 110 sq mi).
Miami River at Miamisburg.	2,718	Miamisburg about 9 miles below Dayton sta.	2,217	1,400	200	200	.43	60,000	21,517	100	60	Normal fluctuation caused by groundwater above station. Flood flow regulated by 4 retarding basins above station.

available from a surface reservoir of given size. Such data may also be helpful in estimating the upper limit of magnitude of ground-water supplies in which stream infiltration is the principal means of replenishment. On the basis that there is no limit to the rate at which water from the stream can enter or be withdrawn from the ground-water reservoir, the theoretical yield from unit storage graphs (described by Cross and Webber, 1950, p. 4) can be estimated in a manner analogous to estimation of the yield of a surface-water reservoir. Thus, on the basis of the unit storage graph prepared by Cross and Webber (1950, fig. 123) for the Miami River at Hamilton (none was presented for the Dayton station) a surface-water reservoir at Dayton having the same storage capacity (approximately 425 billion gal) as the valley-fill deposits would provide a minimum flow, by regulation, of about 1,000 mgd, or about nine times the present water use. The ultimate yield of the ground-water reservoir in the Dayton area will be considerably less than 1,000 mgd, as the water must enter the reservoir principally through streambeds and then move laterally toward points of withdrawal. Entry losses through the streambed and resistance to flow within the aquifer are the principal factors that limit the rate of recharge; the first is more critical than the second. The infiltration rate is influenced by a number of variable factors and, therefore, is not constant; moreover, it can be increased artificially. Thus, within limits imposed by the regimen of streamflow, the yield of the ground-water reservoir at Dayton is largely determined by economic considerations, such as the cost of devising and utilizing methods for increasing the natural rate of recharge.

#### STREAM INFILTRATION

The critical factor in the development of ground-water supplies by inducing infiltration from streams is the rate at which water will "leak" through the streambed into the aquifer. The infiltration rate depends chiefly upon the permeability of the streambed, the permeability and thickness of the underlying aquifer, and the steepness of the hydraulic gradient between the source stream and wells tapping the aquifer. It also depends upon the depth of water in the stream and the temperature of the infiltrating water.

The permeability of the streambed is usually less than that of the underlying aquifer, and for infiltration to occur the water in the stream must be at a higher level than the water table immediately adjacent to the stream. This difference in head is a measure of the force required to move water through the interface between the channel and the body of sand and gravel in which the channel is cut. The relationship between the infiltration rate and the head difference is approxi-

mately linear so long as the water table is not lowered below the streambed. When the water table drops below the streambed and continues to fall, a corresponding increase in the rate of infiltration to the aquifer will not be produced. Until this condition is reached, however, the head available in the stream channel is a major factor affecting infiltration rates.

Seasonal variations in stream temperature may under certain conditions be a major factor in the yield of infiltration supplies (water's viscosity and resistance to flow are inversely related to temperature). The flow rate to a well, for a given drawdown, is decreased about 1.5 percent for each degree the water temperature is lowered. Theoretically, this can amount to as much as a 50 percent change in flow rate over the common range of stream temperature; however, once water enters the ground its temperature quickly approaches a median value and the practical effects of seasonal temperature variations usually are not significant.

The potential yield of wells drawing replenishment from a stream would be easy to evaluate if the rate of infiltration through the streambed could be readily ascertained. Unfortunately, infiltration rates, especially for large streams, are difficult to determine, whether by analysis of ground-water data or by direct measurement of seepage losses in the stream. Borabough (1951, p. 170) stated:

Determination of percolation rates for large streams in terms of rate per unit area is difficult. . . . When a well near a large river is pumped, the cone of depression extends beneath the river until sufficient head and area are developed to satisfy the needs of the system. In a highly permeable bed the cone may extend only part way across the river. Where low vertical permeability exists the cone may expand to include the full width of the stream and then extend up stream and down stream. Since the head distribution is logarithmic percolation rates in the area near the installation will be several times as large as the average over the effective area of percolation.

When sufficient data are available from observation wells in the vicinity of a discharging well or group of wells and an adjacent infiltration stream, contours drawn on the water table will define the size and extent of the cone of depression and show the area of the stream channel in which infiltration is occurring. When the system is in equilibrium and the pumping rate is known, the average infiltration rate can be determined for the area of the stream channel between the limiting or so-called neutral contours, which represent the boundaries of the area in which infiltration is occurring. This method is useful when the aquifer beneath the infiltrating stream is reasonably homogeneous and the shape of the cone of depression is not distorted. Distortion of the cone results from differences in permeability in the aquifer or from the effects of semiconfining beds through which the

water must pass in traveling from the stream to the wells. The complex hydrologic conditions in the Dayton area, particularly effects of the till-rich zone beneath which most wells are screened, together with widespread well-interference effects caused by uncontrolled pumping, generally rule out application of methods based on the areal extent of cones of depression.

The most practical method for determining infiltration rates in the Dayton area is by direct measurement of seepage losses in the streams. However, because of the minimum error of 2-5 percent considered present in all stream-discharge measurements, this method is reasonably accurate only when flows are relatively low and the seepage losses are a significant part of the total flow. The accuracy of the method depends also upon the adequacy of data relative to diversions between measurement points, such as the amount of inflow from storm sewers or tributaries.

The flow in the principal streams at Dayton usually is too high to permit accurate determination of seepage losses by direct measurement. This can be done only when the streams are near their minimum flows; that is, at discharges which are equaled or exceeded about 90 percent of the time. Infiltration rates determined under low-flow conditions may be very different from those which occur when the streams are at moderate to high stages, and this fact must be kept in mind when evaluating the results.

It is generally believed that under natural conditions the rate of infiltration through a streambed is greatest during or immediately after floods, when the silt and other fine-grained sediment, including organic matter, that have accumulated in slack water periods are being removed by channel scour. With reference to Dayton, a board of consultants (Abel Wolman and others, written commun., 1957) stated: "The relatively impermeable river bottom seal or crust that occurs in places in the Miami River greatly retards the vertical seepage of water." The consultants also commented on the indurated character of this "crust," the existence of which, they pointed out, is well known to construction engineers familiar with the river.

A striking illustration of the low permeability of the stream channel in periods of low and moderate flows is a photograph (fig. 14) which shows a difference of several feet between the level of the water in the Miami River and the water table in the Miami Shores area south of Dayton. If the stream channel were more permeable in this area the water table would eventually rise to about the level of the water in the stream.



FIGURE 14.—Excavation near the Miami River in the Miami Shores area, in 1960, showing difference in height between the water table (represented by the water surface in bottom of excavation) and river level. Photograph courtesy of the Miami Conservancy District.



The condition of the streambed depends largely upon the characteristics of flow in the stream, including velocity, sediment load, and erosion or deposition of material in the channel. A stream may scour its channel during rising stages, when the velocity of flow is increasing, and redeposit material during falling stages, when the velocity of flow is decreasing. Moreover, there may be considerable differences in velocity across a stream, and the stream may be eroding one part of its channel and building up another part. Consequently, streambed conditions vary widely from time to time and from place to place. Artificial channel controls such as retaining walls or levees that restrict the flow to a comparatively narrow part of the channel may increase the velocities sufficiently to prevent deposition in a particular reach, while low-head dams, commonly constructed in the major streams to provide for water-supply intakes or to keep the channels flooded for scenic or recreational purposes, increase the siltation of the channels.

Floods are major, still largely unevaluated factors in aquifer replenishment at Dayton. During flood stages in which the streams overflow their banks, water may cover land planted to various kinds of crops, including grass or trees, in various stages of tillage and having a wide range of permeability. Duration of floodflows and the antecedent condition of the ground are also factors determining the quantity of water entering the aquifer. Comparison of the hydrographs of observation wells Mt-2, Mt-3, and Mt-6 and graphs of the mean daily discharge in the Miami River (fig. 15) shows that in June 1958 mean daily flows up to 36,000 cfs lasting for several days raised ground-water levels more than did the well-publicized flood of January 1959, which produced a peak mean daily discharge of nearly 60,000 cfs. Not only were the high discharges of June 1958 of longer duration than those of January 1959, but also, and perhaps more significantly, the 1959 flood occurred when the ground adjacent to the stream channels was largely frozen. The duration of the floodflows and the condition of the ground at the time of the floods controlled the amount of water that infiltrated to the ground-water reservoirs. Still another factor in determining infiltration rates, though in this area probably a minor one, is the amount of soil moisture and the rate at which it is lost by evapotranspiration during flooding.

Stream infiltration rates under natural conditions generally are considerably below rates that have been achieved artificially in some areas by dredging or harrowing of the stream channels, or determined experimentally by allowing water to infiltrate through the bottoms of specially prepared recharge pits. This has led to adoption of artificial recharging methods, such as those used by the Dayton Water Department at Rohrer's Island, and to consideration of the feasibility

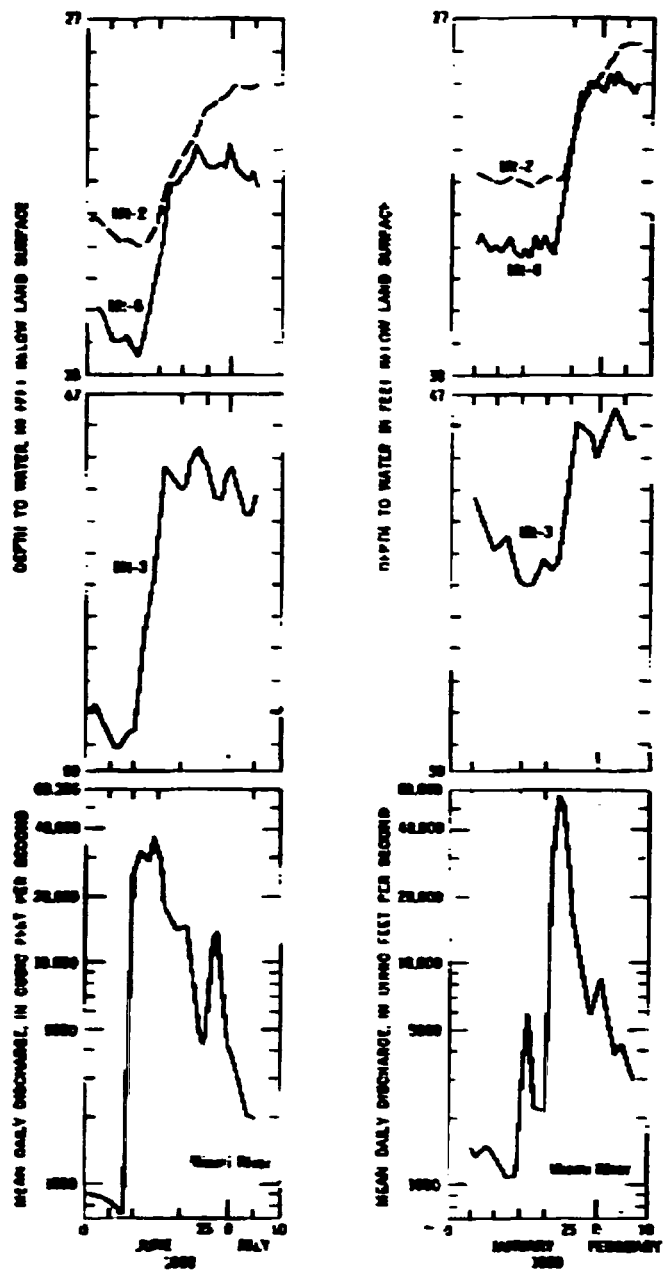


FIGURE 15.—Hydrographs of observation wells Mt-2, Mt-3, Mt-6 and of the Miami River at Dayton, showing effect of riverflow on ground-water levels. Ground-water levels rose more during sustained high flow in June 1968 than during the higher, shorter flow in January 1969.

of applying such methods generally in the Dayton area. The paragraphs that follow review some of the findings on natural recharge rates in other areas and the results of dredging experiments and low-flow studies at Dayton.

According to Rorabaugh (1951, p. 170), infiltration rates through the riverbed in a 2-mile reach of the Ohio River near Charleston, Ind., have averaged 0.15 mgd per acre during periods of intensive pumping. Walton and Scudder (1960, p. 35-36) reported that pumping from wells at the Wright-Patterson Air Force Base has induced infiltration through the bed of Hebble Creek at rates ranging from 0.17 to 0.33 mgd per acre, and through the bed of Mud Run at the rate of 0.34 mgd per acre. These rates are based on discharge measurements made in the summer of 1955 during periods of low streamflow. The rate of infiltration is greater, Walton and Scudder stated, when the flows in the streams are high.

Dove (1962, p. 64) stated that near Hamilton, where as much as 17 mgd is pumped from two large-diameter collector-type wells, the infiltration rate on August 31, 1956, averaged 0.24 mgd per acre in the vicinity of the wells. A further study made by Dove in the summer of 1956 showed the infiltration rate in the same area to range from 0.13 to 0.14 mgd per acre for each foot of head difference between the surface of the river and the subjacent water table.

#### INFILTRATION RATES AT DAYTON

##### ROHRERS ISLAND WELL FIELD

The greater part of the Dayton municipal water supply comes from wells on and near Rohrer's Island (pl. 4). These wells, most of which are screened in the upper sand and gravel aquifer (Norris and others, 1948, p. 53; Norris, 1959), yield an average of about 40 mgd; the peak pumpage has been as high as 90 mgd. The supply is maintained by artificially recharging the aquifer, in what is probably the outstanding example of proper ground-water management in this part of the United States.

Infiltration ditches and lagoons covering a 20-acre area, about one-tenth of the island, have been dredged and are flooded periodically, when the turbidity of the river is low, to recharge the underlying aquifer (figs. 8, 16). Flooding is accomplished (Norris and others, 1948, p. 53) by diverting water from the south channel of the Mad River through a large intake pipe near the head of the island. Flow through this diversion is maintained by a dam in the north (main) channel of the Mad River near the head of the island and by a dam in the south channel about one-third of a mile below the intake pipe (fig. 17). The purpose of these dams is to raise the water sufficiently to



FIGURE 18.—Municipal well field on Rotchers Island.

canoe flow into the infiltration areas. The lagoons and ditches are dredged each year to remove the bottom material and thus maintain a high rate of infiltration through the bottoms of the ponds.

According to Mr. Charles Stout, well-field supervisor, the intake is closed each January and dredging is begun in February. The muck and silt accumulation is dug out with a back hoe down to the clean sand and gravel (fig. 18), and by about May 1 the ponded areas are reflooded. Mr. Stout stated that after the intake is closed, the ponds take about a week to dry up. While the ponds are dry, water levels in the aquifer decline to 30–40 feet below the land surface. During the



FIGURE 17.—Intake structure near head of Rohrer's Island. Gate was closed at time photograph was made.

rest of the year, when the ponds are full, ground-water levels are 10-20 feet below the surface. Methods of maintaining and operating the recharge ponds have changed over the years as various experiments have been made, and they have evolved into the present system, the effectiveness of which is demonstrated by the stability of the water supply over the past several years.

The area subject to infiltration in the vicinity of Rohrer's Island includes not only the 20 acres of ponds on the island, but also two ponds of about 7 acres each lying adjacent to Rohrer's Island on the south bank of the Mad River, as well as the areas covered by the north and south channels of the river (fig. 16). The main channel of the Mad River, where it forms the north boundary of Rohrer's Island, covers an area of about 15 acres at low and moderate stream stages, and the secondary channel of the Mad River, which forms the south boundary of the island, occupies an area of about 7 acres. Thus, the total area on and adjacent to Rohrer's Island through which infiltration can occur is about 56 acres.



FIGURE 18.—Excavations made for artificial recharging of ground water at Rehers Island. Upper photograph shows recharge channel soon after being drained. Mud and silt have accumulated on sides of channel. Lower photograph shows recharge channel after being cleaned and prepared for readmission of water.

Although a large area is subject to infiltration, most recharge to the underlying aquifer, at least during periods of low streamflow, takes place in the 20 acres that is artificially ponded and periodically dredged. Little dredging has been done in the remainder of the area, and relatively little infiltration is believed to occur there.

The U.S. Geological Survey made discharge measurements on and near Rohrer's Island on August 2 and October 19, 1944, to determine the loss of the flow from the Mad River and the loss in ponded areas on the island. The measurements of August 2, 1944, were made at a time when the flow at the Huffman Dam-Mad River gage was approximately 166 cfs, which is equaled or exceeded about 95 percent of the time. A total of nine measurements were made by current meter at points in each channel of the Mad River and in the dredged areas on Rohrer's Island. The total measured loss in streamflow between the upper and lower ends of Rohrer's Island was approximately 30 mgd, of which about 21 mgd was lost in 13 acres of ponded area. Neglecting evaporation losses, this represents an infiltration rate of 1.6 mgd per acre. The total loss in streamflow of approximately 30 mgd was about 82 percent of the water pumped that day from the wells on Rohrer's Island.

The discharge measurements made by the U.S. Geological Survey on October 19, 1944, in the vicinity of Rohrer's Island are inconclusive, owing to a possibly erroneous measurement made in the Mad River below Rohrer's Island. Other measurements on that day indicate a loss in the ponded areas of about 36 mgd, or an infiltration rate of about 2.5 mgd per acre. The flow at the Huffman Dam gage on October 19, 1944, was 162 cfs, or about 96 mgd. Thus, the loss in the ponded areas on that day amounted to more than one-third the total flow in the Mad River.

Discharge measurements were again made in the vicinity of Rohrer's Island by the U.S. Geological Survey on October 4, 1960, as part of a low-flow study based on measurements made at several points on the Mad and Miami Rivers, between the Huffman Dam gage and the mouth of Holes Creek. At the time the measurements were made the discharge at the Huffman Dam gage was 182 cfs, about 16 cfs more than the discharge on August 2, 1944.

The measured loss in flow in the vicinity of Rohrer's Island between station A, the Huffman Dam gage, and station B, about 400 feet below Harshman Road (pl. 4), was 31 mgd. Mr. Charles Stout estimated that when the U.S. Geological Survey made its measurements in 1960, about 30 mgd of water was entering the ponded areas on Rohrer's Island, most of it flowing into six of the northernmost group of ponds on the island, which have a total area of about 15 acres. According to Mr. Stout, there was very little infiltration from the remainder of the

ponds on and near the island and from the Mad River because of the silted condition of these other areas. (The diversion into the ponds on Rohrer's Island reduces velocity in the Mad River and increases siltation in the reach of the river adjacent to the island.) If it is conservatively estimated that 25 mgd was infiltrating through the beds of the six ponds, the infiltration rate was about 1.7 mgd per acre, which is nearly the same as the rate determined from the August 2, 1944, measurements.

Pumpage at Rohrer's Island on October 4, 1960, was 28 mgd from the upper aquifer and 12 mgd from the lower aquifer. The measured loss in flow of 31 mgd between stations A and B represents nearly 80 percent of the water pumped on that day.

#### DISCHARGE MEASUREMENTS OF SEPTEMBER 7, 1961

On September 7, 1961, the U.S. Geological Survey made two discharge measurements on the Mad River, at the Huffman Dam gage and near its mouth, and two measurements on the Miami River, at the Main Street gage and near the Broadway Bridge in the southern part of Dayton. The discharge at the Huffman Dam gage was 235 cfs, about 20 percent greater than the flow on October 4, 1960. No data were obtained on effects of diversions between the measuring stations; however, the Mad River measurements indicate a loss of about 43 mgd between Huffman Dam and the mouth of the stream. The greater part of this loss probably occurred in the ponded areas on Rohrer's Island.

#### DISCHARGE MEASUREMENTS OF OCTOBER 4, 1960

On October 4, 1960, engineers of the U.S. Geological Survey and the Miami Conservancy District measured the discharge at several points on the Miami and Mad Rivers to determine the amount of water entering the ground by seepage through the streambeds and to ascertain the areas in which the rate of infiltration was significant. On the day the measurements were made the flow of Miami River at Dayton was only 205 cfs, which normally is exceeded 98 percent of the time, and the flow at the Huffman Dam gage was 182 cfs. At such a low stage, measurements in the Miami River can ordinarily be made by men wading the stream.

Six measurements were made, and these were supplemented by discharge figures computed from gage readings at the Dayton gage and the Mad River gage at Huffman Dam. One measurement in the Miami River, about a mile above the mouth of Holes Creek, was made from a boat and was considered too inaccurate to use in the study. However, another measurement was made in the same place, reached by wading, on October 26, when the stream stage was the same as it had



been on October 4. The October 26 measurement is consistent with those of October 4 and is used in this analysis.

Conditions of stream stage and ground-water use were relatively constant for several days prior to the time of the measurements and remained so for several days thereafter. Light rains fell throughout Ohio on October 1 and 2, when a total of 0.40 inch was recorded at the Dayton Municipal Airport. This caused a rise of about 0.1 foot at the Dayton gage on the Miami River, which crested at midnight on October 2. Recession was gradual, and the stage was nearly constant by October 4.

To determine more accurately the gains or losses in discharge between successive measurement points, inflow from the city storm sewers and the major industrial plants and the effluent from the sewage treatment plant were recorded at or about the time the measurements were made. Discharges from the city storm sewers were computed on October 3; however, in the opinion of Mr. Elmer Gooch, Chief Engineer of the Bureau of Sewers, they were virtually the same as the flows of the previous day.

The points where the stream measurements were made are shown on plate 4, and the discharge data and rates of infiltration between successive stations are given in table 4. As expected, the greatest loss in flow, 31 mgd, occurred in the vicinity of Rohrer's Island between stations A and B. Infiltration took place chiefly in the ponded areas on the island, as has already been described.

TABLE 4.—Miscellaneous discharge measurements, October 4, 1938

Measurement station	Approximate location	Discharge	Inflow between stations	Gain or loss between stations		Area of stream bed (acres)	Infiltration rate (mgd per acre)
				cfs	mgd		
A	Mad River at Huffman Dam	132					
B	Mad River at Harshman Rd.	134				15	1.7
C	Mad River above Findlay St.	126		-8	-8.3	13	.60
D	Mad River near mouth	127	10	+1	+6	18	
E	Miami River at Main St. gage	285	80	-12	-7.7	25	.33
F	Miami River below Broadway Street Bridge	293	44.3	-14.3	-10.8	180	.66
H	Miami River opposite Miami View Golf Course	300	74.3	-1.3	-1.8	35	.02
I	Miami River 1 mile north of Hales Creek	300	7.8	-20.8	-13.4	40	.38

<sup>1</sup> It is estimated that all but 6 mgd entered the ground through 15 acres of pond area; hence,  $\frac{26}{15} = 1.7$ .

<sup>2</sup> Represents only those ponds on Rohrer's Island through which most infiltration occurred.

<sup>3</sup> Effluent from sewage-treatment plant.

<sup>4</sup> Measured Oct. 26, 1938.

Discharge measurements at stations B and C (pl. 4) show a loss in flow of about 8 mgd in the reach of the Mad River between Harshman Road and a point about 0.4 mile above Findlay Street. Ground-water

withdrawals in this part of the valley, chiefly from municipal wells C-7 and C-8, were estimated to be about 3.5 mgd on October 4. Recharge to these wells probably accounted for part of the loss in flow in this reach of the river; some of the loss may relate also to the filling of cones of depression around wells C-17 and C-18, from which about 4 mgd was being pumped up to a few hours before the measurements were made. Much of the loss in this reach was due also to pumping from the lower aquifer farther downstream, between stations C and D. Infiltration was facilitated by stream dredging then in progress in the vicinity of well C-17, about 2,000 feet below Harshman Road. The dredging had been going on intermittently all summer in this general area as part of a program of levee construction and channel straightening.

On the basis of the total area of the streambed between measurement points B and C, the infiltration rate was computed to be about 0.4 mgd per acre. However, infiltration was probably not uniform over the area, and the infiltration rate in the dredged areas no doubt greatly exceeded the rate calculated for this segment of the stream.

In the reach of the Mad River between measurement points C and D, from a point 0.5 mile below Eastwood Park nearly to the confluence with the Miami River, there was little change in flow. Pumping in this area of the valley amounts to about 3-5 mgd from the lower aquifer and to little or none from the upper aquifer. The piezometric surface of the lower aquifer is below river level in this area (pla. 7, 8), and some vertical leakage from the upper to the lower aquifer, and consequent loss of streamflow by infiltration to the upper aquifer, would be expected. However, hydrologic conditions in this part of the valley are altered by the presence of a local confining bed of till which occurs at shallow depth in the upper aquifer. The shallow till layer forms a local artesian aquifer which receives recharge from the unconfined part of the aquifer in the vicinity of Eastwood Park. A part of this recharge reaches the lower aquifer by downward leakage through the till-rich zone.

In the short reach of the Miami River between station D, near the mouth of the Mad River, and station E at the stream-gaging station about 1,000 feet below the Main Street Bridge, and including a 2,000-foot reach extending upstream from the mouth of the Mad River to station K, there was a loss of about 7.7 mgd based on the discharge measurements of October 4, 1960. The infiltration rate in this area was about 0.3 mgd per acre, a little less than that determined for the reach of the Mad River between stations B and C, below Rohrer's Island.

The loss in flow between stations D and E results from pumpage of about 10 mgd in the central part of the city, which has lowered the

piezometric surface of the lower aquifer as much as 20 feet below river level.

The October 4, 1960, discharge measurements show a loss of about 10.5 mgd between stations E and F, in the 3.5-mile reach of the river between the gaging station near the Main Street Bridge and a point below the Broadway Bridge, near the south limits of Dayton. Pumpage in this area is relatively heavy, currently averaging 25-30 mgd. As plate 8 shows, the piezometric surface of the lower aquifer is 20-35 feet below river level. Ground-water levels along this reach of the stream are the lowest in the Dayton area owing to a relatively low rate of infiltration, which on October 4, 1960, was only 0.06 mgd per acre. As a consequence of the low infiltration rate, more water was being removed from aquifer storage along this reach of the river on October 4, 1960, than along the rest of the channel.

The low infiltration rate between stations E and F is probably due to a greater accumulation of silt there than elsewhere, caused by the pooling of the river behind the low dam at the Tait Station of the Dayton Power & Light Co. In 1936 a board of consultants (Abel Wolman and others) made tests near Carillon Park, about 0.5 mile above the Tait Station Dam, and found that as much as 1 foot of fine-grained sediment generally covered the river bottom. At that time the water table was 8-12 feet below river level in the Carillon Park area.

On the basis of pumping-test data and the hydraulic gradient, the board of consultants estimated that on May 21, 1956, the Miami River was losing water in the test area near Carillon Park at the rate of 10 mgd per mile of channel. This estimate is much higher than that based on the measured loss in flow on October 4, 1960, of 10.5 mgd between stations E and F, which is equivalent to only 3 mgd per mile of channel. The discharge at the Dayton gage on October 4, 1960, was 205 cfs, and on May 21, 1956, it was 935 cfs. The higher discharge on May 21, 1956, would probably have resulted in a higher infiltration rate than occurred on October 4, 1960. However, the rate of 10 mgd per mile of channel, estimated near Carillon Park, cannot be applied to the entire 3.5-mile reach between stations E and F, and no comparison can be drawn between it and the infiltration rate determined on October 4, 1960.

Between stations F and H, in the 1.8-mile reach between a point near the south boundary of Dayton and a point opposite the Miami View Golf Course, south of the city sewage-treatment plant, there was little change in flow on October 4, 1960. Allowing for the diversion into the Miami River of the effluent from the sewage plant, there was

a measured loss in flow of only 0.8 mgd, a quantity too small to consider in view of the margin of error inherent in the discharge measurements.

There is very little pumpage in the reach between stations F and H; however, the cone of depression around the Tait Station wells to the north and that around the Frigidaire Division wells to the south merge in this area, and the piezometric surface of the lower aquifer is a few feet below river level. The hydraulic gradients are very low, however; this fact, plus the fact that ground-water recharge is received from the kame deposits that lie along the east edge of the valley, accounts for the small loss in streamflow on October 4, 1960.

In the reach of the Miami River between station H, near the Miami View Golf Course, and station I, 1 mile north of Holes Creek, the loss in streamflow was estimated to be about 12 mgd, on the basis of the discharge measurements of October 4 and 24, 1960. For the entire reach between stations H and I, the infiltration rate was about 0.8 mgd per acre. About 26 mgd is currently being pumped in the area adjacent to this reach of the stream, and the piezometric surface of the lower aquifer generally is a few feet below river level. Some water was being pumped from storage in the aquifer on October 4, 1960, and some of this was being replaced by flow from the kame deposits along the east edge of the valley. These permeable sand and gravel deposits, which extend south from Calvary Cemetery to Holes Creek, constitute a large natural reservoir which absorbs much precipitation and releases it slowly as ground-water discharge to the Miami River. (See geologic section B-B', pl. 2.) Wells drilled in the valley between the river and the bordering kame deposits receive recharge from both sources.

Approximately 110-120 mgd was being pumped for municipal and industrial water supply in the Dayton area when the October 4, 1960, discharge measurements were made. These measurements show that about 50-55 percent of the water pumped from the ground was being replaced by induced stream infiltration. The remainder was being pumped from storage in the aquifer, except for a minor amount derived from inflow from the hills bordering the valleys. The measurements were made when the flow at the Dayton gage on the Miami River was 305 cfs, a discharge that is equaled or exceeded nearly 99 percent of the time (pl. 2). During the periods of such low flows the rate of infiltration from the rivers, except at Rohrer's Island, is too low to keep pace with the quantity of water being pumped. Consequently, ground-water levels decline until infiltration from the streams becomes more effective in recharging the aquifers.

## INFILTRATION AS RELATED TO STAGE, DISCHARGE, AND AREA

Comparison of the hydrographs of wells Mt-2, Mt-3, and Mt-6 to the mean discharge in the Miami River (pl. 2) shows that the annual fluctuations in ground-water levels follow closely the hydrograph of mean stream discharge. The highest ground-water levels usually lag behind the peak stream discharges by periods of a week or more; however, ground-water levels usually begin to rise from their seasonal lows in the early fall, when the streams still are at fairly low stages. The annual rise in ground-water levels in downtown Dayton begins at the end of the air-conditioning season, when pumpage is reduced.

Sustained discharges greater than about 2,000 cfs<sup>2</sup> at the Miami River (Main St.) gage produce most of the annual recharge to the ground-water reservoirs in central and southern Dayton. This is concluded from a comparison of the hydrographs of observation wells Mt-2, Mt-3, and Mt-6 to mean daily discharges in the Miami River (fig. 19) for 1956, a fairly typical year. It is not known whether the rate of infiltration is directly proportional to stream discharge and becomes sufficiently large when the discharge is about 2,000 cfs to exceed the present rate of withdrawal from the aquifers, or whether at some "critical" discharge a sudden disproportionate significant increase in the infiltration rate is produced. This may occur when the velocity reaches a point where scouring of the streambed begins; or it may relate to changes in the width of the channel, in that at higher discharge more of the channel is flooded than at lower discharge, allowing water to infiltrate in areas where the indurated channel deposits of muck and silt have not accumulated in significant amount.

A table follows that shows the relationship between discharge, stage, width, and velocity of stream at the Main Street gage (Miami River at Dayton).

Discharge (cfs)	Stage (ft)	Width of stream (ft)	Velocity (ft per sec)	
			Mean	Highest
125.....	10			
200.....	.18	292	0.60	1.08
300 <sup>1</sup> .....	.34	299	.74	1.30
2,000.....	1.96	357	1.75	2.67
10,000.....	5.88	451	4.08	4.64

<sup>1</sup> Gage-height datum is alt 729.9 ft.

<sup>2</sup> Discharge equaled or exceeded about 90 percent of the time.

<sup>3</sup> A discharge of 2,000 cfs at the Main St. gage is approximately equivalent to a discharge of 650 cfs at the Huffman dam gage on the Mad River.

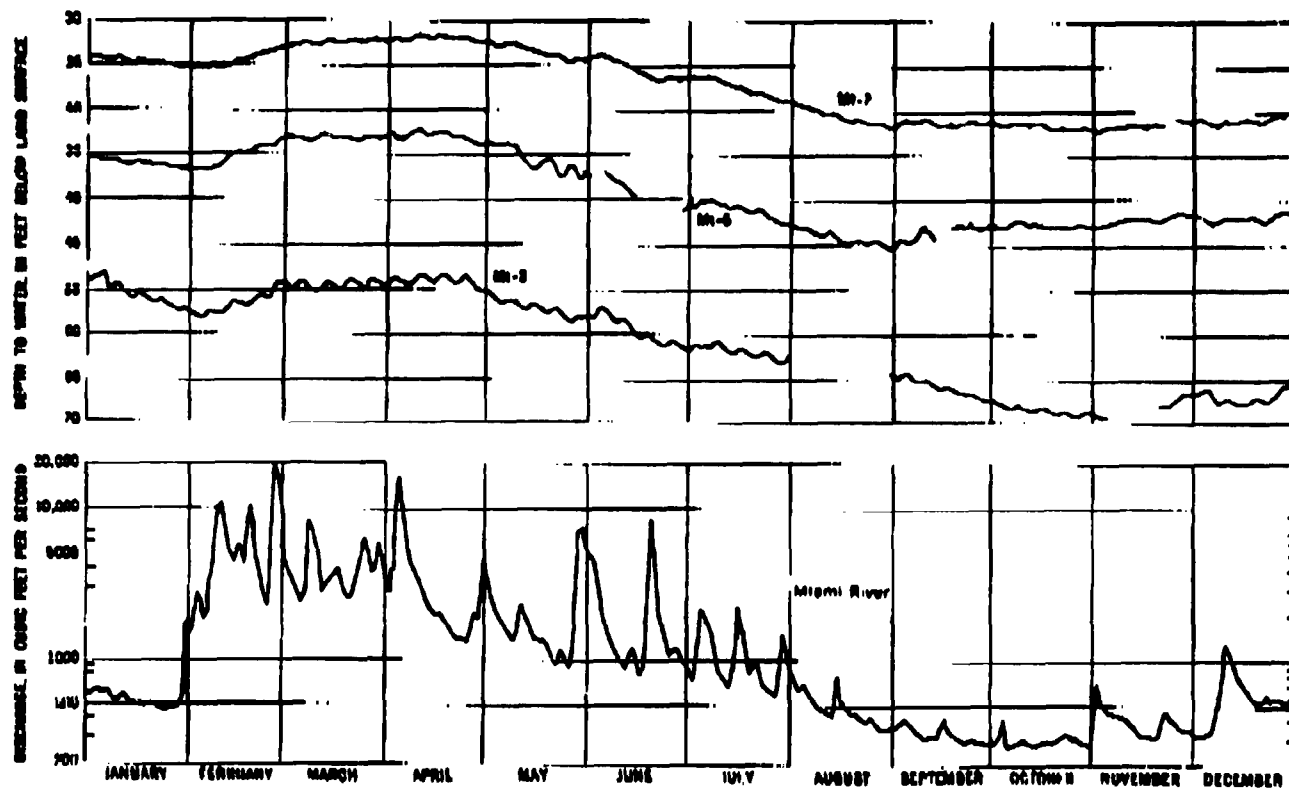


FIGURE 19.—Hydromographs of observation wells Mt-4, Mt-5, Mt-6 and of the Miami River at Dayton, 1956. Ground-water levels generally rise when discharge equals or exceeds about 2,000 cfs.

The relationship between width of the stream and specific discharge varies considerably between the Main Street gage and the low-head dam near the south limits of the city. The Miami River is more restricted below than above the dam, and width below the dam changes relatively little when discharge is 300-2,000 cfs.

In the vicinity of the Main Street gage the width of the stream changes little between stages of 6 and 9 feet. Below a stage of 6 feet, however, the infiltration rate may at times be significantly higher in the part of the channel lying between the "normal" water's edge and the waterline represented by a discharge of, say, 2,000 cfs. The intermittent exposure of this area, during which the ground is dried out, may temporarily increase its permeability.

The change in stage between discharges of 300 and 2,000 cfs is only about 1.6 feet at the Main Street gage, and the depth of water in the stream is not a significant factor in determining the amount of water infiltrated in downtown Dayton. Farther downstream, however, in the vicinity of Moraine City, the stage changes more with variations in discharge, and the head in the river has relatively greater influence in the recharging of the underlying aquifers.

At a discharge of about 30,000 cfs at the Main Street gage, levees are topped in the unimproved part of the channel, and infiltration can occur over a considerable area in the lowlands south of Dayton. A discharge of 80,000 cfs occurs, on the average, about once each  $1\frac{1}{2}$  years, according to records of the Miami Conservancy District, often enough for widespread flooding to be a major factor in recharging the ground-water reservoirs. Improvements will eventually be made which will restrict flows of this magnitude to the existing channel, limiting the areas that will be flooded and probably reducing ground-water recharge.

Infiltration rates are related also to the velocity of flow in the stream, in that at critical velocities the silt and indurated bottom seal may be scoured from the streambed, thereby increasing its permeability. Velocities at which a stream scours its bed vary greatly and depend upon the condition of the streambed, the sediment load in the stream, and the kind of sediment being transported. The effects of increased permeability of the streambed, caused by scouring, are partly offset by the higher turbidity of the water during floods, which reduces infiltration.

Engineering studies to determine the effects of the flow of water on bed materials have been directed toward the design of stable channels and permissible canal velocities, and little attention has been given to the relation of flow characteristics to infiltration rates. King (1939,

p. 284), commenting on the work of Fortier and Scobey (1926), stated that:

there is no sharp line of demarcation between the velocities that can no longer maintain silt in movement and those that will scour a canal bed. It is believed that there is a broad belt of velocities between these two "critical" velocities within which silt already loosened or brought in through a headgate will remain in suspension while the bed will not be scoured. In general, old and well-seasoned canals will stand much higher velocities than new ones. This is true particularly if the canal bed or if the silt conveyed by the stream contains colloidal matter.

King (1939, p. 286) presented a table, also based on the work of Fortier and Scobey, listing permissible canal velocities after aging. Part of the table follows in modified form.

Original material concerned	Velocity (ft per sec)		
	Clear water, no debris	Water transporting colloidal silt	Water transporting noncolloidal silt, sand, gravel, or rock fragments
Fine sand, noncolloidal.....	1.30	2.50	1.50
Fine gravel.....	2.50	5.00	3.75
Coarse gravel, noncolloidal.....	4.00	6.00	6.30

A more nearly complete table listing permissible velocities for use in the design of silt-stable canals was published in the U.S.S.R. in 1936 and presented in a report by Simons.<sup>2</sup> In modified form, it is as follows:

Material	Diameter (mm)	Mean velocity (ft per sec)	Material	Diameter (mm)	Mean velocity (ft per sec)
Silt.....	0.05	0.05	Pebbles.....	15	3.94
Sand:			Fine.....	25	4.38
Fine.....	.05	.05	Medium.....	40	4.91
Medium.....	.25	.25	Coarse.....	75	7.37
Coarse.....	1.00	1.00	Large.....	150	9.86
Gravel:			Do.....	300	12.32
Fine.....	2.00	2.15	Do.....	600	14.80
Medium.....	5.00	2.62	Do.....	1200	17.28
Coarse.....	10.00	3.20			

These velocities, according to Simons, are modified by a correction factor which varies with depth as follows:

Depth.....ft.	0.95	1.97	3.28	4.92	6.58	8.20	9.84
Correction factor.....	.90	.90	1.00	1.10	1.15	1.20	1.25

The foregoing discussion of permissible velocities in artificial channels cut in various materials is useful as a general guide in considering the effects of flow velocities in the natural stream channels at Dayton. Velocities vary considerably in the Miami and Mad Rivers, not only with discharge, but also with changes in width of the channels from

<sup>2</sup> Simons, D. B., 1937, Theory and design of stable channels in alluvial materials: Fort Collins, Colorado State Univ. Ph.D. thesis, p. 2-66.



place to place. Suffice it to say that in many places and at various times velocities in these streams are sufficiently high that streambeds are eroded. The effects of this erosion on the "bottom seal" have yet to be evaluated in terms of the relation between infiltration rates and specific flows in the streams.

#### GROUND WATER AVAILABLE FROM NATURAL STREAM INFILTRATION

In the reach extending upstream from Holes Creek to the Miami River well field of the city of Dayton, the Miami River at moderately low stages covers an area of approximately 400 acres. At comparable stages the Mad River, between its mouth and Huffman Dam, covers an area of approximately 75 acres, including 20 acres of ponds and lagoons on Rohrer's Island.<sup>4</sup> Thus, during low to moderate stages a total of about 475 acres of streambed is covered by water. During higher discharges the streams cover somewhat more area; for the purpose of this discussion it is assumed that at discharges of about 2,000 cfs at the Main Street gage the total area covered by the streams is about 550 acres. Ground-water pumpage in this area totals approximately 110 mgd, of which an estimated 85 mgd is replenished by infiltration through the streambeds. Therefore, if infiltration occurs uniformly over the entire 550-acre area of streambed, the average infiltration rate will be approximately 0.15 mgd per acre, a value considerably below that observed in many places under natural conditions. It is understood, of course, that ground-water recharge does not occur uniformly over the area, but ranges from zero in small areas where the streams are gaining, to at least 1.7 mgd per acre in the ponded areas on Rohrer's Island.

The highest rate of natural infiltration through the bed of the Miami River is in the reach extending from the mouth of the Mad River to the vicinity of the Broadway Street Bridge, near the south boundary of Dayton. Pumpage along this 4-mile reach is about 30 mgd, almost all of which, owing to the impermeable covering of buildings and city streets, must be replenished by infiltration through approximately 165 acres of streambed. Ground-water levels are below the streambed perennially in this area, and infiltration from the Miami River occurs all the time, though at varying rates. On an annual basis the infiltration rate averages about 0.18 mgd per acre. However, the average infiltration rate in most of this area was only 0.06 mgd per acre on October 4, 1960, during a period of low stream discharge. As explained previously, most recharge is associated with discharges at the Main

<sup>4</sup>The stream-covered areas were computed from aerial photographs taken Aug. 18 and 26, 1956, when the discharges at the Main St. gage were 450 and 375 cfs, respectively.

Street gage of about 2,000 cfs, or greater, which occur about 20 percent of the time.

If the infiltration rate is assumed to average 0.08 mgd per acre 80 percent of the time when the discharge is less than 2,000 cfs, it must average about 0.6 mgd per acre during the rest of the year to replenish the approximately 30 mgd being pumped. An infiltration of 0.6 mgd per acre is greater than that measured in any part of the natural stream channels on October 4, 1960, and it may be close to the maximum that occurs naturally in this part of the channel when most recharge occurs. This is consistent with results of dredging experiments made by the board of consultants, which showed that, locally at least, the "channel seal" was relatively impermeable in this area.

Because of the low average infiltration rate, ground-water development in this part of the Miami River valley, that is, in the central and southern parts of Dayton, has nearly reached its practical limit. Overdevelopment has occurred locally as ground-water levels have declined in the past 4 or 5 years in places where pumpage has not increased. The decline was halted only temporarily, in 1957, 1958, and early 1959, when discharge at the Main Street gage was above average. The year 1958 was unusual in that the discharge in most of June, July, and August exceeded 2,000 cfs and, as a result, the seasonal decline in ground-water levels was much less than normal. With ground-water levels already abnormally high, the spring recharge of 1959, which was heralded by near-record-breaking floods, raised ground-water levels to highs that had not previously been reached since 1952. This recovery was short lived, however, and by the summer of 1960 ground-water levels in observation wells Mt-2 and Mt-6, in downtown Dayton, were at record lows. The water level in observation well Mt-3, in the southern part of Dayton near the Stewart Street Bridge, was near the low of record in 1960 and probably would have been at an alltime low had there not been a reduction in pumpage that year at nearby plants.

Pumpage has been reduced in places because of the lowering of ground-water levels; elsewhere, pumping levels are near the tops of the well screens in relatively deep wells, and shallower wells have been abandoned. These conditions have been noted at the National Cash Register Co. plant in south-central Dayton, at the Delco Products Division plant in central Dayton, and at the Third Street Station of the Dayton Power & Light Co., in the east-central part of town.

Pumpage can be increased locally in central and southern Dayton by the drilling of new wells in relatively undeveloped parts of the area. Increases obtained this way will be small, however, compared to the total quantity of water now being pumped in the area, and they cannot be depended upon to keep pace with the increase in water use.

Most land is already preempted, and water users are limited in their choice of drilling sites. Substantial increases in pumpage in this part of Dayton must await development of methods for increasing stream infiltration to the underlying aquifers.

Ground-water development can be increased in the Miami River valley in the northern part of Dayton, above the mouth of the Mad River, because pumpage there is only about 4 mgd and ground-water levels are relatively high. Much of this area is a residential section, however, and future pumpage is not likely to exceed 10-15 mgd, a quantity which can be readily obtained. The quantity of ground water available in this area will be reduced eventually by development of the new municipal well field in the Miami River valley, about a mile north of the city limits.

North of Dayton the aquifers were virtually untapped until the municipal water department began development of its new Miami River well field in the vicinity of Beardshear Road. Pumpage at the new well field was only about 8 mgd in the spring of 1961; however, water-department officials hope to develop ultimately a supply of 50 mgd from the well field by artificial recharging methods similar to those used at Rohrer's Island.

Hydrologic conditions at the new well field are not nearly as favorable as they are at Rohrer's Island for the development of a large ground-water supply. At the new well field the upper aquifer is comparatively thin and most of the wells will necessarily be screened in the lower aquifer, beneath the till-rich zone. Development of 50 mgd of water will be a practical undertaking only if the rate of leakage through the till-rich zone proves to be comparatively high.

About 10 percent of the time the flow of the Miami River at Taylorsville, 7 miles above the new well field, is less than 60 mgd (Cross and Hedges, 1959, p. 139). After the well field is fully developed, pumpage at times of greatest demand, coincident with periods of low streamflow, will virtually dry up the stream in the area of the well field. At such times the quantity of ground water available in Dayton will be reduced, especially north of the mouth of the Mad River, into which area the cone of influence of the well field will probably spread. Farther south, in central and southern Dayton, ground-water levels may be lowered moderately in drought periods when, unfortunately, they are already critically low in some areas.

Ground-water development in the Mad River valley in the vicinity of Rohrer's Island is near its practical limit. The municipal water department pumps more than 40 mgd on an average, from wells in the upper and lower aquifers. This amount is replenished chiefly by infiltration through lagoons and ditches on Rohrer's Island. In the

summer, peak demand of more than 90 mgd frequently comes when the flow in the Mad River is so low that most of the water enters the ground in the area of the well field.

The large diversion at Rohrer's Island must be considered in plans for additional development farther downstream; however, between Rohrer's Island and the mouth of the Mad River conditions locally are favorable for additional large-scale development. In 1925, before the first well was drilled on Rohrer's Island, the city pumped about 90 mgd from groups of wells in the Mad River valley below Rohrer's Island.

An area of exceptionally good potential in the lower Mad River valley is that between Eastwood Park and Findlay Street, where the geologic evidence indicates a break in the till-rich zone and where, as a consequence, the sand and gravel deposits form a single relatively thick aquifer of high transmissibility. The city has already drilled wells C-42, C-43, C-44, C-45, and C-46 on or near the levee in this area and is presently pumping an average of about 8 mgd, with little lowering of ground-water levels. The possibilities for large-scale development might be further increased by the use of one or more abandoned gravel pits in this area to recharge the aquifer artificially.

The Miami River south of Dayton, between the Broadway Bridge and the mouth of Holes Creek, covers an area of approximately 110 acres at relatively low flow. If the stream were confined to this channel at all times, the quantity of water available naturally from induced infiltration could reasonably be estimated as 50-75 mgd annually. Presently, however, channel improvements are generally lacking in this reach, and flows of about 30,000 cfs, which occur on the average about once each 1½ years, result in the flooding of large areas of bottom land. These floodflows contribute substantially to the re-filling of the ground-water reservoir, and in this area they enable larger withdrawals than will be possible in the future, when channel improvements are made and levees are heightened.

As a final note in this section, some mention should be made of potential for ground-water development in the Stillwater River valley in the northwestern part of Dayton. The Stillwater River is underlain by deposits of sand and gravel, but the deposits generally are thinner and of much less areal extent than those in the other principal valleys. Moreover, the Stillwater River flows mostly through a residential area in which large ground-water supplies probably will not be developed. Locally, however, there are sites along the river where ground-water supplies of perhaps as much as 1-2 mgd can be developed.

**LEAKAGE THROUGH THE TILL-RICH ZONE**

The rate at which water will move through the till-rich zone into the lower aquifer is a major factor determining the availability of ground water in some areas. In the vicinity of Rohrer's Island the till-rich zone is relatively effective as a confining bed, and the piezometric surface of the lower aquifer averages about 30 feet lower than the water table as a result of the pumping of about 15 mgd from the lower aquifer (Norris, 1959, p. 14). The till-rich zone probably is equally effective as a confining bed in much of the downtown and northern parts of Dayton and more locally in areas south of Dayton, such as the vicinity of Moraine City. The till-rich zone is relatively ineffective as a confining bed in the Mad River valley in the Findlay Street-Eastwood Park area, where interbedded till deposits are generally thin or absent, and also in the vicinity of the Tait Station of the Dayton Power & Light Co., in South Dayton, where the till-rich zone comprises lenses and irregular masses of till.

In the Miami River valley the piezometric surface of the lower aquifer is about 10-30 feet below the water table in heavily pumped areas. It can be lowered an additional 20-30 feet in most places without dewatering the lower aquifer. If the water table is maintained at a relatively high level, providing a large potential head difference between water in the upper and lower aquifers, pumpage can increase substantially before the rate of leakage through the till-rich zone becomes a major limiting factor.

Figure 20 shows, for various leakage coefficients, the quantity of water that will leak through the till-rich zone under various head differences between the upper and lower aquifers in a segment of the valley 1 mile long where the valley-fill deposits are assumed to average 2.5 miles in width. In the Dayton area the value of the leakage coefficient has been determined only at one place, on Rohrer's Island, where it ranges from 0.002 to 0.012 gpd per cu ft. If a median value of the leakage coefficient is selected, 0.007 gpd per cu ft for example, the graph shows that for a head difference of 30 feet between the upper and lower aquifers about 14 mgd will leak through the till-rich zone in a valley segment 1 mile long and 2.5 miles wide.

**ARTIFICIAL RECHARGING METHODS**

Aquifers have been artificially recharged through either injection wells or specially constructed pits or by land flooding, and people have asked whether artificial recharge would be feasible at Dayton. Although a detailed treatment of the subject is beyond the scope of this report, some of the principal factors to be considered in evaluating certain methods of artificial recharging are presented here. A brief

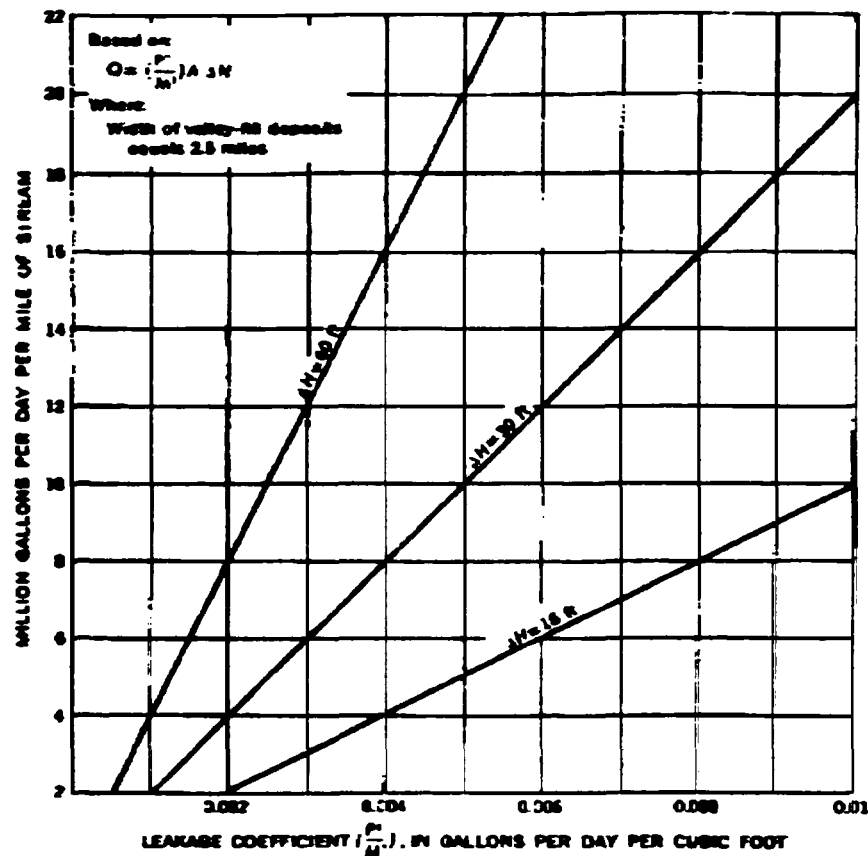


FIGURE 28.—Quantity of water that will leak through the till-rich zone at various values of the leakage coefficient and selected head differences in the aquifer.

description is given of dredging experiments in the Dayton area and of engineering studies on specially constructed recharge pits at Peoria, Ill.

#### EXPERIMENTS IN THE DAYTON AREA

Artificial recharging is not new to the Dayton area, as recharge ponds have been used with considerable success for several years by the Dayton Water Department at Rohrer's Island. Also, a recharge pit about one-third of an acre in area is used each summer at the Frigidaire Division plant in Moraine City to dispose of 1-1.5 mgd of waste water. This pit is dredged about every 6 weeks while it is in use.

Recharge through wells is an attractive possibility, as water can be injected into an aquifer at rates comparable to rates of pumping

from the aquifer. Injection wells, like supply wells, require proper development for efficient operation. Also, injection wells must receive clear water or they will eventually become clogged. The chemical quality and temperature of the water used for recharging must be such that no adverse effects, such as precipitation of mineral compounds, result from mixing of this water with the water already in the aquifer. The temperature of the injected water may be critical also with respect to the use of the ground water for certain industrial purposes, and this may limit the time of year when recharge from surface-water sources can be carried on. Finally, the available head or pressure difference between the water being injected and the water in the aquifer must be considered, as this factor is major in determining the rate at which water can enter the aquifer.

In 1955 the Miami Conservancy District experimentally determined infiltration rates through the bed of a small recharge pit dug in a dry part of the Miami River channel. The pit, a quarter of an acre in area, was 500 feet downstream from the Main Street Bridge (pl. 4) and dug to a depth of 2 feet below river level. When the experiment was made the water table was several feet below the bottom of the pit.

As reported by a board of consultants (Abel Wolman and others, written commun., 1957), the infiltration rate was as high as 7 mgd per acre when unfiltered river water was first conveyed to the pit. The infiltration rate declined rather rapidly, however, and in one experiment it fell to approximately 0.65 mgd per acre at the end of 2 weeks. The decline was believed due to progressive silting of the pit bottom and to a reduction in the ground-water gradients in the vicinity of the pit caused by the building up of a ground-water mound beneath the pit.

This experiment attests to the very large increase that can be effected initially in the rate of streambed infiltration by artificial means, such as dredging, but it also points up the necessity of taking into account, in assessing the benefits of artificial recharging, the very rapid decline in efficiency of many common methods.

The Miami Conservancy District also made a recharge experiment in 1954 in south Dayton, on the right bank of the Miami River opposite Carillon Park, in an area where the water table was more than 10 feet below river level. The board of consultants (Abel Wolman and others, written commun., 1957) reported that:

In this recharge test water was siphoned from the river over the top of the levee and into a large gravel pit nearby. The siphon action was started by means of a pump. Once established, the siphon was allowed to continue for a number of days. The gravel pit acted as a large recharge basin and allowed the siphoned river water to infiltrate into the ground-water system. No detailed data on water levels or infiltration rates were collected during this experiment. The main conclusion to be derived from the test was that operations of this type can successfully put large amounts of water into underground storage.

The board of consultants also experimented with artificial recharging methods in the spring of 1936 by dredging the channel of the Miami River in a small area near Carillon Park (pl. 4), where the water table was about 18 feet below normal river level. As stated by the board:

the chief purpose of this experiment was (1) to evaluate rates of river infiltration under natural conditions, and (2) to observe changes in these rates caused by artificially removing the upper few feet of river-bottom materials.

The test program involved the installation of numerous observation wells on both banks of the river and in the river channel itself. Measurements of water level in these wells were made periodically to determine changes in the profile of the water table across the stream channel with reference to changing conditions of river stage. When sufficient data had been obtained to permit an evaluation of natural rates of river infiltration, the river bottom was dredged to a shallow depth, and further observations made of the resulting effects on increased infiltration \* \* \*.

During the installation of some of the observation wells in the river channel, frequent water-level measurements were made inside and outside the pipe to determine the exact position of the water table with reference to river level. In every instance, as soon as the well screen had penetrated more than a foot below the channel floor, the water standing in the pipe ran out into the highly permeable deposits at these shallow depths. The water table was not encountered until the well points had been driven to a depth of approximately 12 feet below river level \* \* \*.

Except in a small area near the right bank, where several feet of silt had accumulated on the river bottom, the thickness of the channel seal at the probe sites was nowhere greater than about one foot. At most of the test sites, the standing water in the probe drained out after only about 8 to 10 inches of penetration into the channel bottom. The deposits below the channel seal were found to be highly permeable and carried water away as rapidly as it could be poured into the pipe \* \* \*.

At the infiltration-test site, the water table was encountered below the channel floor at depths that varied from as little as three feet in wells in the deepest part of the channel to as much as 12 feet in wells along the river's edge \* \* \*.

The most significant feature of the natural profile is the water-table ridge whose crest is almost directly below the deepest part of the river channel. This crest represents the highest elevation of the water table in the area and the flow of ground water must, therefore, be away from it \* \* \*.

In May 1938, after several months of water-level and temperature observations, arrangements were made to remove the river-bottom seal in a strip 20 feet wide and 300 feet long, oriented parallel to the shoreline and located about 40 feet from the left bank \* \* \*.

On May 21, a three-quarter-yard dragline, operating from the left bank, began cutting into the channel floor near well 13 [number not in accordance with system used in present report] and about 40 feet off-shore. The first attempts to remove material from the river bottom were unsuccessful and the dragline bucket contained practically no material when taken out of the water. This difficulty in breaking through the "crust" on the river bed had been anticipated by the dragline operators and by engineers and other construction workers familiar with the river \* \* \*.

The cutting teeth on the dragline bucket were then inverted to provide a more satisfactory bite. After one or two cuts which brought up no material from the



channel floor, the cutting teeth finally penetrated the deposits and the bucket was removed from the river partly filled with silt, sand, and gravel. The next few bites into the channel floor were made at about the same location and the bucket was brought up full or partly full each time. After making a total of five or six cuts, the operation was suspended temporarily to permit water-level measurements to be made in several of the nearby observation wells \* \* \*.

The materials brought up from the first few cuts in the channel floor consisted chiefly of very coarse sand and gravel, with cobbles up to about six inches in diameter. Many of the pebbles and cobbles were stained dark black and the finer sand and gravel had a pronounced black appearance. After brief exposure to air and sunlight, the black color faded almost completely. The sediments brought up later from several feet below the crust were texturally similar, but were light gray in color instead of black.

Within a matter of minutes after the channel-bottom seal had been penetrated, water levels in nearby observation wells began to rise as a result of increased river infiltration \* \* \*.

\* \* \* Water levels in wells very close to the dredged strip reached their highest levels on the last day of dredging operation, when infiltration rates were probably at a maximum. A slow decline of water levels in these wells began shortly thereafter \* \* \*.

The relatively impermeable river-bottom seal or crust that occurs in places in the Miami River greatly retards the vertical seepage of water. Although the experimental dredging operation temporarily removed the seal in a small area, subsequent flood flows tended to quickly reveal the dredged cut with silt. Thus, it seems likely that dredging operations would have to be carried on almost continuously if any lasting increase over the natural rate of infiltration were to be attained \* \* \*.

Increasing the rate of river infiltration by dredging in the losing stream areas would raise ground-water levels by only moderate amounts. The maximum rise of water levels would be no greater than the original difference between stream level and the underlying water table. In most places, this rise would be on the order of only a few feet, although rises of perhaps as much as 25 feet could take place at some sites. Pumping lifts in production wells near the river would be somewhat reduced and the yields would be increased slightly, but as discussed previously, it is thought that a considerable part of these benefits would be short-lived.

In view of the factors outlined above, dredging of the channel floor will accomplish little more than to raise ground-water levels locally near the river \* \* \*.

In areas where concentrated pumping has extensively lowered ground-water levels, consideration should be given to recharging the underground reservoir by the basin method rather than by channel dredging, particularly in areas at considerable distances back from the Miami River.

#### EXPERIMENTS AT PEORIA, ILL.

In view of the board of consultants' suggestion relative to the possibility of recharging the aquifers through basins, information is presented on the results of basin experiments at Peoria, Ill. The Illinois State Water Survey Division conducted infiltration experiments over a period of several years, beginning in 1951, in two shallow recharge pits dug in glacial outwash deposits in this heavily pumped industrial area of the Illinois River valley. Other experiments also made use of

a recharge pit dug by the Bemis Bros. Bag Co. at Peoria. Results of this work were described by Suter and Harneson (1960) in a bulletin of the Illinois State Water Survey.

Filter materials, consisting of several sizes of sand and of sand and gravel mixtures, were placed on the pit bottoms in the Peoria experiments, and river water of varying temperature and turbidity was channeled into the pits. The filter materials were cleaned or replaced several times in the course of the experiments to discover which material had the least tendency to become clogged by the sediment in the river water. The authors stated (1960, p. 31) that:

In general it has been observed that the types of silt materials in the river govern the effects on recharge to an extent equalling or exceeding the turbidity concentration. Strong winds create waves which scour the fine muds from the bottom of Peoria Lake. Turbidity created in this manner was persistent and rapidly clogged the filtering surface of the recharge pits. In many instances, higher concentrations of turbidity which were caused by excessive storm runoff were less persistent and had less effect on the recharge rate.

Suter and Harneson (1960, p. 45) summed up the results of the Peoria recharge-pit experiments as follows:

The problem of finding a method of recharge to meet the needs peculiar to Peoria has been solved. By means of pits, artificial recharge is conducted at high infiltration rates; operating costs are low in comparison to the cost of treating river water for direct use; practical methods of maintaining satisfactory infiltration rates have been developed; ground-water temperatures have been maintained within desirable limits; and a significant contribution has been made toward stopping the recession of local ground-water levels.

Maximum infiltration rates of 175 feet per day<sup>1</sup> have been reached in the experimental Pit No. 2 constructed by the Water Survey, and rates higher than 200 feet per day have been achieved in the pit of Bemis Bros. Bag Company. Mean annual rates for three successive seasons of concurrent operation of the two Water Survey recharge pits were between 102.8 and 54.5 feet per day in Pit No. 2 and between 41.2 and 38.7 feet per day in Pit No. 1.

Valuable information has been obtained relative to operating procedures and costs. The cost summaries show that the operating cost has been approximately two cents per thousand gallons recharged. This is substantially less than the limit of six cents per thousand gallons which had been estimated as the maximum to be attractive commercially. The unit cost of recharge was reduced during the years that both pits were operated for the reason that the quantity of water recharged was increased while the cost of supervision of operation remained almost constant. It appears that advantage lies with annual replacement of filter media because it enables higher recharge rates. Unit costs per thousand gallons recharged were almost identical whether the pit was cleaned annually or operated two or three years between cleanings.

Experience has demonstrated the ability of pea gravel to serve as an effective filtration media [sic], while allowing a practical rate of infiltration over long periods of time. Bacterial analyses of samples taken since the pea gravel was

<sup>1</sup> Author's note: The height of a column of water filtering through a well of surface area is 20 in.; an infiltration rate of 1 ft is equal to about 0.32 mgd per acre.

first used have shown no deterioration in sanitary quality of the ground water. Repeated use of the pea gravel caused no significant reduction in the average daily recharge rate in Pit No. 1 and resulted in slight reductions in the rate of Pit No. 2. The pea gravel was replaced after three seasons of use because the concentration of silt was approaching the saturation limit of its void spaces.

Temporary increases in recharge rate can be obtained by removing part of the accumulated silt with a suction cleaner. Although the benefits of such cleaning are immediately apparent, they are short-lived \* \* \*.

The statements by the board of consultants on dredging experiments at Dayton and by Suter and Harneson on the operation of recharge pits at Peoria, Ill., indicate that from an engineering standpoint, both methods of artificial recharge are probably feasible in the Dayton area. The problem remains, however, of determining how feasible these methods are in terms of cost and how to assess the benefits to individual users.

#### GROUND-WATER PUMPAGE IN THE DAYTON AREA

The Dayton area, where the average pumpage in 1958 was about 110 mgd, has the largest concentration of ground-water use in Ohio and one of the largest in the Midwest. The population and industrial production of the area are certain to increase during the next few decades, and water demands will increase concurrently. The present density and distribution of pumpage and the course of development of this pattern are fundamental to an evaluation of the ground-water potential of the area.

The hydraulic properties of the glacial-outwash deposits vary throughout the area, and some of the deposits can sustain a higher rate of pumping than others. Their development, however, has to some extent been haphazard and has not necessarily been greatest in the most favorable areas.

An inventory of ground-water pumpage in the Dayton area was made in 1954-55 by Mr. Robert E. Reemelin of the Water Conservation Subdistrict of the Miami Conservancy District. Supplemental data were collected by the authors in 1957-59, which brought the inventory up to date. Ninety-five industries that pump ground water and three public water-supply systems were surveyed with regard to average daily pumpage, peak pumpage, and the history of pumpage.

Figures given for the 3 public-supply systems in the area are accurate, as these systems meter their water and maintain pumpage records; however, only 4 of the 95 industries inventoried keep such records. Figures for the remaining 91 industries are estimates based on the number and capacity of wells and the number of hours per day each pump operates. These estimates range in accuracy from excellent to highly questionable. Most of the estimates of present water consumption are probably fairly accurate, whereas some of the histori-

cal data are more dubious. Very little of the information is recorded; it is usually kept only in the memory of a plant engineer or maintenance foreman, who may not remember exactly how much water his plant used 20 or 30 years ago. While lacking in detail, these figures do represent the order of magnitude of ground-water pumpage in years past.

Use of ground water in the Dayton area (table 5, fig. 31) has increased tenfold since 1900. Generally speaking, pumpage was at first concentrated in downtown Dayton and then spread gradually into the outlying areas, though not equally in all directions. To facilitate the discussion of pumpage distribution, the Dayton area has been divided into six districts (pl. 5), within the boundaries of which are the principal centers of pumping. Some of the larger districts have been subdivided because pumpage is concentrated in only a part of the district or at several separate centers. District boundaries wherever possible coincide with natural features, such as streams and the bedrock walls of the buried valleys, but in places they are arbitrary.

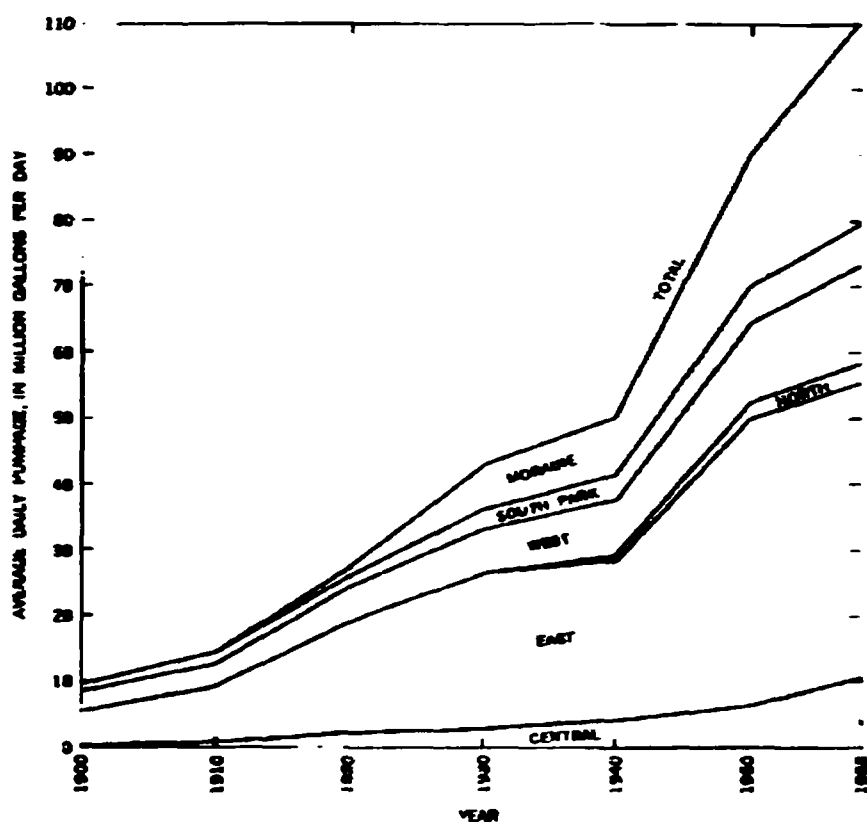


FIGURE 21.—Ground-water pumpage in the Dayton area by districts, 1900-58.

TABLE 5.—History of ground-water pumpage in the Dayton area by districts, 1900-58

Year	Central district		East district		North district		West district		South Park district		Moraine district		Total of all districts
	Avg daily pumpage (mgd)	Percent of total in Dayton area	Avg daily pumpage (mgd)	Percent of total in Dayton area	Avg daily pumpage (mgd)	Percent of total in Dayton area	Avg daily pumpage (mgd)	Percent of total in Dayton area	Avg daily pumpage (mgd)	Percent of total in Dayton area	Avg daily pumpage (mgd)	Percent of total in Dayton area	
1900.....	0.06	0.9	8.30	53.6	.....	0	2.80	34.8	1.04	10.8	.....	0	9.92
1910....	.49	3.4	8.84	51.6	.....	0	2.78	34.5	1.64	10.7	.....	0	14.85
1920.....	2.13	7.8	16.78	51.7	0.08	.3	8.08	19.6	2.04	7.5	1.08	4.6	27.17
1930.....	2.77	6.6	23.75	55.7	.06	.2	6.26	14.7	3.17	7.4	5.86	15.4	42.61
1940.....	4.19	8.4	34.13	66.1	.89	1.2	8.64	17.3	4.02	8.6	8.38	17.1	61.15
1950.....	6.06	7.1	48.06	68.5	2.63	2.9	11.81	13.1	5.82	6.6	19.65	21.8	81.01
1958.....	10.21	9.3	66.73	41.4	3.06	2.8	14.96	12.5	8.78	8.1	20.83	27.0	119.47

Table 6 is a summary of ground-water pumpage in the Dayton area, showing for each district the average daily pumpage, area, and pumpage density in million gallons per day per square mile. Table 7 is a detailed record of pumpage by districts, showing pumpage in 1935, the number of wells, number of days per year in operation, and use of water by each industry inventoried.

TABLE 6.—Summary of average daily ground-water pumpage, and area and density of pumpage in the Dayton area, Ohio, 1935

District	Average daily pumpage (mgd)	Area (sq mi)	Pumpage density (mgd per sq mi)
Central.....	10.21	1.80	5.68
East.....	44.73	7.24	6.15
Eastern part.....	38.55	4.35	8.38
Western part.....	10.18	2.89	3.54
North.....	3.06	15.18	.20
Area of actual pumping.....	2.06	2.37	.91
West.....	12.86	7.37	1.88
Eastern part.....	12.86	5.01	2.77
South Park.....	6.78	1.17	5.80
Moraine.....	29.83	10.45	2.84
Western part.....	29.83	5.88	5.03
Total for Dayton area.....	110.47	43.23	2.56
Total for area actually sustaining pumpage.....	110.47	27.75	3.99

TABLE 7.—Pumpage of ground water by public-supply systems, industries, and commercial establishments in the Dayton area, Ohio, 1935

Use of water: A.C., air conditioning; B., boiler makeup; C., cooling or refrigeration; IRR., irrigation; P., processing; S., sanitary; W., washing.

Establishment	Number of active wells	Number of days per year in operation	Pumpage in 1935 (millions of gallons)			Use of water
			Yearly	Average daily	Estimated daily peak	
Central district						
Delco Products Div., General Motors Corp.	7	300	1,170.0	2.250	4.300	P, A.C., S
Freightliner Div., General Motors Corp. (plant 1)	2	300	305.0	1.000	1.000	AC
Commercial Film	2	300	230.0	.600	1.000	AC, S
Dayton Power & Light Co.						
Longworth St. Pk.	3	300	204.0	.300	1.000	B
Barnhill Cold Storage Co.	2	300	200.1	.600	.000	C, S
Hino-Kramer Co.	5	300	600.0	.600	1.200	AC, A, B
Miami Valley Milk Producers Association	2	300	100.0	.300	1.000	C, W
Ice Cream Div., Borden Co.	1	300	172.4	.000	.000	C
Milk Div., Borden Co.	1	300	100.0	.300	.000	C
Dayton Power & Light Co., Ed. Bldg.	3	300	100.0	.300	.300	B
Hider & Johnson Co.	2	213	32.0	.200	.700	AC, S
Miami Hotel	1	300	60.0	.200	.300	AC, S
Sims Bookbinder & Co.	1	100	60.3	.200	.000	AC

See footnote at end of table.

## GROUND-WATER PUMPAGE IN THE DAYTON AREA 111

TABLE 7.—Pumpage of ground water by public-supply systems, industries, and commercial establishments in the Dayton area, Ohio, 1958—Continued

Establishment	Number of active wells	Number of days per year in operation	Pumpage in 1958 (millions of gallons)			Use of water
			Yearly	Average daily	Estimated daily peak	
Central district—Continued						
Holman Bldg.	1	135	87.7	0.196	0.003	AC
Ohio Bell Telephone Co.	2	365	86.7	.180	.393	AC
Bacon Store	1	180	81.8	.142	.350	AC
Dayton Power & Light Co., 6th St. Sta.	1	365	44.0	.120	.120	C
King Koles Restaurant	1	286	43.6	.116	.330	C, W, S
Miller Bldg.	2	286	38.9	.103	.300	AC
Dayton Coca-Cola Bottling Co.	1	286	38.8	.109	.300	S, P, W
Gas & Electric Bldg.	1	286	27.9	.074	.130	AC
CIO (IUE) Local 801 Hall	1	198	20.8	.068	.280	AC
Model Laundry	1	280	18.4	.052	.073	W
Talbot Bldg.	1	133	18.4	.052	.280	AC
Domestick's, Inc.	1	286	18.1	.068	.073	AC
Metropolitan Clothing Co.	1	108	18.1	.080	.280	AC
Third National Bank	1	180	18.2	.049	.119	AC
McCreary's 8 & 10 cent Store	1	132	15.3	.043	.280	AC
Neefe Dairy	1	365	14.6	.040	.098	W, C
Gibbons Hotel	1	365	12.8	.036	.093	AC, B
Leave Bldg.	1	132	11.1	.061	.114	AC
Leaves Theater	1	140	10.5	.080	.180	AC
Columbia Theater	1	140	8.8	.024	.180	AC
Fraternity Order of Eagles	1	120	8.6	.028	.180	AC
Rosenthal-Harriet-Harman Co.	1	132	8.5	.024	.180	AC
Rialto Theater	1	188	4.2	.011	.080	AC
Westminster Church	1	132	3.2	.008	.154	AC
Ottoborn Press	1	280	2.6	.007	.018	B, C
Gendert & Liansch, Inc.	1	280	2.0	.006	.016	B, S
East district						
City of Dayton well fields	46	365	16,880.0	46.780	70.003	PS
Marter Electric Co.	1	365	128.6	.360	.300	C, P, F
Fuchs Packing Co.	2	365	78.3	.216	.300	P
Hewitt Soap Co.	1	200	60.6	.110	.360	C, W
J. J. Roskoma Co.	1	365	38.4	.106	.110	C, W
Sheffield Corp.	1	182	38.0	.104	.300	C
White Clover Dairy	1	365	9.9	.027	.080	W, C
Farm Bureau Co-op Association	1	200	8.6	.026	.080	B, C
Dayton Packing Co.	1	365	2.0	.006	.006	C
B. C. Davis Co.	1	120	0.6	.002	.005	AC
North district						
Chrysler Airtemp Sales Co.	3	365	478.0	1.308	1.403	P, B, AC
Keystone Sand & Gravel Co.	1	198	121.6	.332	.758	W
G.H.F. Foundry Div., Dayton	2	310	124.9	.330	.780	P
Malleable Iron Co.	2	365	112.5	.308	.378	P
Dayton Rust Proof Co.	1	286	86.7	.243	.482	C, S
Burdette Oxygen Co., Rita St.	1	286	46.4	.128	.220	C, W, S
Premier Rubber Co.	1	286	31.4	.088	.150	C, W, S
Stolls Corp.	1	158	27.6	.074	.208	C
Kant Dayton Tool & Die Co.	1	268	20.8	.057	.123	W, S, AC
D. W. Marshall Co.	1	146	16.2	.045	.150	AC
Salera Theatre	1	132	15.6	.043	.280	AC
McCook Bowling Co.	1	200	13.1	.036	.073	W, P
Golden Age-Dayton Co.	1	308	10.6	.030	.080	AC
Burdette Baking Co.	1	208	1.9	.004	.007	C
Burdette Oxygen Co., McCook Ave.	1	280	0.6	.002	.008	W, S
Price Bros. Co.	1	280	0.6	.002	.008	W, S

See footnote at end of table.

TABLE 7.—Pumpage of ground water by public-supply systems, industries, and commercial establishments in the Dayton area, Ohio, 1932—Continued

Establishment	Number of active wells	Number of days per year in operation	Pumpage in 1932 (in thousands of gallons)			Use of water
			Yearly	Average daily	Estimated daily peak	
West district						
Edison-Memphis Div., General Motors Corp.	4	365	1,455.0	4.000	1.000	P, R, C
Antonia Paper Co.	8	365	1,250.0	3.400	1.500	P, C, W
Dayton Tire & Rubber Co.	8	365	750.0	2.000	1.000	P, C, W
Edison Bros. Dairy	3	365	725.0	1.900	1.000	P, C, W
Starchless Starches, Inc.	3	315	725.0	1.900	1.000	P, C, W
City Products Corp.	2	365	550.0	1.500	1.000	P, C, W
Starch Packing Co.	3	315	550.0	1.500	1.000	P, C, W
Dayton Sheet Foundry Co.	1	365	450.0	1.200	1.000	P, C, W
Gen. City Ice Cream Co.	2	365	447.0	1.200	1.000	P, C, W
Specialty Paper Co.	1	315	418.0	1.100	1.000	P, C, W
Dairy Div., Kruger Co.	1	365	344.0	1.000	1.000	P, C, W
Standard Rubber Co.	1	120	22.5	.060	.060	AC
Kellogg Bros. Cereals	1	365	25.0	.070	.070	C, AC
Monsanto Chemical Co.	3	120	20.0	.050	.050	AC
Lee Rubber Co.	1	365	20.0	.050	.050	P, C, AC, W, S
Devine-Young Soap Co.	1	365	20.0	.050	.050	AC, P
Stamaco-Wardens-White Co.	1	365	14.5	.040	.040	C, P
Wolf Creek Soap Co.	2	365	4.7	.010	.010	C, P
National Foundry & Furrows Co.	1	335	2.1	.005	.005	P, S
South Park district						
National Cash Register Co.	9	365	2,570.0	7.000	2.000	P, C, P, AC, S
City of Oakwood	3	365	102.0	.275	.000	PS
Madison district						
Edison Div., General Motors Corp. (Mansfield City plant)	20	365	7,350.0	20.000	20.000	C, W, P, AC
Montgomery County Sanitary Dept.	7	365	1,000.0	2.700	10.000	PS
Dayton Power & Light Co.	5	365	1,000.0	2.700	4.000	C
Frank M. Tuck & Co.	1	365	200.0	.500	.500	C, W
Ad. Robertson Sales Co.	3	365	140.0	.400	.500	P, C, W
M. O. Snyder & Sons, Inc.	1	365	60.0	.160	.200	AC
Dayton Power & Light Co., Service Bldg.	1	120	61.0	.160	.200	AC
National Cash Register Co. Golf Course	2	120	61.3	.160	1.000	IRR
Dayton Community Golf Course	1	120	30.2	.080	.200	IRR
City of Dayton, Mound View Golf Course	1	120	9.1	.025	.000	IRR
Monsanto Div. Co.	1	365	2.4	.007	.000	B, S, AC
South Dayton Hotel	1	365	2.4	.007	.000	S
Chas. Bickel Co.	1	365	2.1	.005	.000	B, C, S
Dayton Brick Co.	1	365	1.0	.003	.000	W, C, S

<sup>1</sup> Pumping largely restricted to summer season.

#### CENTRAL DISTRICT

The Central district of the Dayton area is bounded on the north and west by the Miami and Mad Rivers; the rest of the boundary is arbitrary—a circle of 1-mile radius whose center is at the corner of Third and Main Streets.

It might be expected that the Central district would be the first to undergo significant ground-water development, but it hasn't. By 1900 the district was fairly well developed residentially and com-



mercially, and little room remained for industry. The earliest industries were located in the West and South Park districts. The two large plants in the Central district, the Frigidaire and Delco Products Divisions of General Motors Corp., began operations long after 1900.

Pumpage has increased at a steady rate from 0.08 mgd in 1900 to 10.21 mgd in 1958. The Central district accounted for only 0.8 percent of the water pumped in the Dayton area in 1900, but this percentage had risen to 9.3 by 1958. Most of the percentage increase occurred between 1900 and 1920; from then to the present it has been in the range of 6-10 percent.

The pumpage density of 5.7 mgd per sq mi for the Central district is well above the average of 2.5 mgd per sq mi for the Dayton area as a whole. Forty establishments in the district withdraw ground water, but only two—the Delco Products and Frigidaire Divisions of General Motors Corp.—use 1 mgd or more. A large part of the water pumped in the Central district is used to air-condition office buildings; hence the daily pumpage during the summer far exceeds the average daily figure, which is based on the entire year.

The Central district, already saturated with commercial and residential establishments, is not likely to undergo extensive industrial development in the future. Any increase in pumpage here will likely be due to increased air conditioning of office buildings and will be small compared to increases that are likely to occur elsewhere.

#### EAST DISTRICT

The pumpage history of the East district can be virtually equated with the history of the Dayton municipal water system. Formerly, all the municipal wells were located here; this situation recently changed, when the Miami River well field, in the North district, began operation. The East district sustains very little pumpage other than from the municipal well fields.

Pumping of ground water by the municipal system began in 1869 from large-diameter dug wells at the corner of Dutoit and Beacon Streets, and 2 years later new wells were drilled at the corner of Keowee and Ottawa Streets. In 1887 a group of 8-inch wells was drilled along the Mad River just east of the main pumping station at Keowee Street. The number of wells increased with the city's population and water demands (Norris and others, 1948, p. 52-56). The "old main group," begun in 1887, expanded to 94 wells and by 1909 was supplemented by another group of 6 wells, the "aqueduct group." From 1914 to 1919, 28 wells were installed at Taits Hill and 11 at Eastwood Park. In 1926 development began of the present well field, centered at Rohrer's Island. Drilling of additional and more efficient

wells there and along the banks of the Mad River has brought about gradual abandonment of the older wells from 1926 to the present. Municipal pumpage has spread from the area of the Keowee Street pumping station eastward along the banks of the Mad River, until now nearly the entire East district along the river is within the area of influence of the municipal wells.

Systematic records of municipal pumpage prior to 1910 are not available. In 1910 the municipal wells yielded an average of 8.53 mgd, or 59.3 percent of all water pumped in the Dayton area. Municipal pumpage, estimated at about 5 mgd in 1900, had increased to 45.75 mgd by 1968. The percentage of all water pumped in the Dayton area that is pumped by the municipal fields has decreased to about 40, whereas pumpage by privately owned industrial and commercial establishments has greatly increased.

Pumpage in the East district other than that from the municipal well fields has never totaled more than about 8 percent of the water pumped in the Dayton area.

The average of 45.8 mgd pumped by the Dayton municipal water system came from three centers (pl. 5). About 37.8 mgd came from 48 wells at and near Rohrer's Island, about 5 mgd came from 5 wells along the south bank of the Mad River at Taits Hill, and about 3 mgd came from one well near the water-treatment plant, on the south bank of the Mad River east of Keowee Street. Pumpage from other establishments, mostly small industries, totals about 1 mgd, a relatively insignificant figure compared with the municipal pumpage.

Pumpage density for the East district is 6.45 mgd per sq mi, well above the average for the Dayton area. A better idea of pumpage distribution in the East district can be obtained by dividing the district in two along a line approximately normal to the Mad River at Taits Hill. The eastern part of the district, which includes all the municipal wells at Rohrer's Island, has an area of 4.36 square miles, sustains an average daily pumpage of 36.55 mgd, and has a pumpage density of 8.38 mgd per sq mi. The western part has an area of 2.88 square miles, sustains an average daily pumpage of 10.18 mgd, and has a pumpage density of 3.54 mgd per sq mi. These figures clearly show that the eastern part of the district sustains far more pumpage than the western part. The eastern part has the highest pumpage density in the Dayton area, whereas the western part has a considerably lower density.

If any part of the Dayton area can be said to have reached its maximum feasible pumpage, it is either the eastern part of the East district or the South Park district. If pumpage in the first area were substantially increased, excessive drawdowns and a higher cost of lift would result. Officials of the city of Dayton have recognized that

the well field in the vicinity of Rohrer's Island is being pumped near its capacity, and they are therefore developing a well field adjacent to the Miami River north of Dayton to meet future demands.

#### NORTH DISTRICT

No pumping of ground water is known to have taken place in the North district prior to 1920; furthermore, pumpage did not exceed 1 mgd until the period from 1940 to 1950. By 1958, it had increased to 3.06 mgd, or nearly 3 percent of the total pumped in the Dayton area.

The North district is largest (15.18 sq mi) of the six divisions of the Dayton area. Only 3.38 square miles in the industrial part of North Dayton (pl. 5) sustains substantial ground-water pumpage. With an average pumpage of 3.06 mgd, this district has a pumpage density of 0.9 mgd per sq mi, the lowest computed for any part of the Dayton area.

In view of its particularly low pumpage density, the North district is one of the most promising parts of the Dayton area for future development of large ground-water supplies. The city of Dayton's Water Department purchased land north of Dayton, along the west bank of the Miami River, and is developing a new well field, which went into limited use in 1960. When the new well field is fully developed, the North district will undoubtedly be among the more heavily pumped parts of the Dayton area.

#### WEST DISTRICT

During the past 60 years the West district has accounted for a substantial part of Dayton's ground-water pumpage. Prior to 1930 most of this water was pumped by the Aetna Paper Co., whose average daily pumpage, 3.5 mgd, has remained virtually unchanged since 1900. Many companies, engaged in different industries, have since located in the West district and in 1958 the average pumpage had increased from the 3.5 mgd of the Aetna Paper Co. to 13.86 mgd. The West district's percentage of the water pumped in the Dayton area has declined, however, from 35.3 percent in 1900 to 12.5 percent in 1958. This does not mean to imply that the West district has correspondingly dropped in importance as a supplier of ground water. In the late 1920's, industrial expansion began there in earnest, and since then the district's percentage of the total has not declined appreciably (table 5, fig. 21); it even rose to 17.2 percent temporarily in 1940.

In 1958, 20 establishments accounted for the average daily pumpage of 13.86 mgd in the West district. Three of these—the Aetna Paper Co., the Dayton Tire & Rubber Co., and the Delco-Moraine Division of General Motors Corp.—each have an average daily pumpage in ex-

cess of 1 mgd. With the exception of these three large plants, pumpage is rather evenly distributed through the eastern part of the West district.

The eastern part of the West district, an area of 5.01 square miles (pl. 5), had a pumpage density of 2.77 mgd per sq mi in 1958, which is nearly the average for the Dayton area. The district as a whole had a pumpage density of 1.88 mgd per sq mi.

Pumpage in much of the West district is near its practical limit; however, close to the Miami River it could be increased without causing excessive drawdowns.

#### SOUTH PARK DISTRICT

The National Cash Register Co. has accounted for the bulk of ground-water pumpage in the South Park district since 1900. Its pumpage increased from about 1 mgd in 1900 to an average of 6.5 mgd in 1958. Beginning in 1927 the Oakwood municipal waterworks has withdrawn an average of 0.381 mgd, in addition to pumpage of The National Cash Register Co. This figure has remained constant despite the increase in Oakwood's population. The pumping capacity of the Oakwood waterworks is limited by its location near the edge of the buried valley, where the permeable sand and gravel deposits are relatively thin and are too far from the Miami River to receive recharge from infiltration. The additional water demands have been met by purchase of water from the city of Dayton and the Montgomery County Sanitary Department.

The percentage for the South Park district of all water pumped in the Dayton area dropped from 10.5 percent in 1900 to 6.1 percent in 1958; this decline reflects the relatively more rapid industrial expansion of other districts.

The National Cash Register Co. pumps its average of 6.5 mgd from nine wells distributed through the north half of the district. The bulk of its pumpage comes from three wells north of Stewart Street near the east bank of the Miami River. The Oakwood waterworks is located near the southeast border of the district.

The pumpage density in the South Park district is 5.80 mgd per sq mi, well above average for the Dayton area.

The South Park district is not likely to experience much increase in ground-water pumpage in the future. Drawdowns in the National Cash Register Co. wells are already so great that plant engineers feel it would not be prudent to pump more water. Many test wells have been drilled throughout the district with generally unfavorable results.

**MORaine DISTRICT**

No significant pumpage of ground water in the Moraine district was recorded prior to 1915, when the plant now belonging to the Frigidaire Division of General Motors Corp. started production with an initial average daily pumpage of about 1 mgd. Late in the 1920's the Frank M. Tait Station of the Dayton Power & Light Co. began operation, and in 1930 it and the Frigidaire Division plant together pumped an average of 6.5 mgd. Since World War II, pumpage in the Moraine district has shown a spectacular increase—from 8.58 mgd in 1940 to 29.83 mgd in 1958.

In 1952 the Lamme Road well field of the Montgomery County Sanitary Department began pumping at an average rate of 2.4 mgd, which had increased to 5.37 mgd by 1958. A small but undetermined part of the total during the period 1956-58 was pumped from the well field at Dryden and Sellars Roads.

The Moraine district has shown the most rapid rise of all the districts with respect to percentage of water pumped in the Dayton area. Pumpage in this district increased from only 4 percent in 1920 to 27.0 percent in 1958.

Pumpage in the Moraine district is largely concentrated at the north and south ends of the western part (pl. 5). The three principal establishments which account for 95 percent of pumpage in the district are the Frank M. Tait Station of the Dayton Power & Light Co. at the north end, and the Frigidaire Division of General Motors Corp. and the Montgomery County Sanitary Department well fields at the south end.

An accurate representation of the pumpage density in the Moraine district is difficult to construct. The density for the entire district is 2.84 mgd per sq mi. Excluding the eastern part (pl. 5), which sustains no substantial pumpage, the rest of the district has a pumpage density of 5.03 mgd per sq mi. Even this figure is not completely representative, owing to the uneven pumpage distribution discussed above. Computing the pumpage density of arbitrary areas around these pumpage centers would be misleading, owing to the difficulty in defining boundaries for such areas. Suffice it to say that the pumpage density around the two principal centers of pumpage is considerably higher than the average for the district.

Pumpage in the Moraine district will probably continue to increase, though perhaps not at the phenomenal rate from 1940 to 1958. The eastern part of the district probably won't share in the expansion, as it is almost entirely residential. The rest of the Moraine district, however, has much land suitable for industrial growth. Even the present pumpage centers can stand some further development without

excessive drawdowns. The Moraine district is probably destined for more industrial growth than any other part of Dayton, and ground-water pumpage there can be expected to increase accordingly.

Possibly the greatest expansion of ground-water pumpage in the future will result from increase in output of the well fields of the Montgomery County Sanitary Department. This public-supply system, whose pumpage grew from nothing in 1951 to 5.37 mgd in 1958, seems destined for further expansion. The county is constantly extending its water mains to new areas; almost all new housing developments in Montgomery County south of Dayton will be served by the system. To meet these increased water demands, the county is developing a new well field south of Miami Shores (pl. 5). Conceivably this system could attain the magnitude of the Dayton municipal water system.

#### GROUND-WATER LEVELS IN THE DAYTON AREA

The need for systematic water-level records is seldom recognized until long after pumpage has become intensive. This is indeed true in the Dayton area, where the longest continuous water-level record, that of observation well Mt-2, dates from 1942; most of the others begin in 1945 or later. Thus ground-water levels cannot be accurately related to increasing pumpage except in the more recent years.

A well-rounded program of water-level record should relate water-level measurements to both time and area. The importance of the time element was recognized when, in 1942, the cooperative observation-well program was begun by the Ohio Engineering Experiment Station and the U.S. Geological Survey. In 1946 this program was expanded and made permanent (Kaser, 1956, p. 1). In more recent years a few of the larger industries and public water suppliers have recognized the need for systematic water-level records and have established their own observation wells.

Necessary though it is, the observation-well program does not fully meet the need for water-level information in a large and hydrologically complex area such as Dayton. Here enters the element of area. At best, the half dozen or so observation wells in the Dayton area provide a continuous record of the water level at only a half dozen or so locations. These few points are not sufficient to define the piezometric surface of an extensive aquifer and its many centers of pumpage (pl. 5), and the cost of drilling and maintaining a sufficient number of observation wells would be prohibitive.

The element of area in water-level records was considered during the present investigation. In the spring of 1955, Mr. R. E. Boemelin of the Water Conservation Subdistrict measured the water levels of

about 80 wells in the Dayton area. In 1958, personnel of the U.S. Geological Survey resumed measurement of these wells in the fall and spring of each year. Plates 7 and 8 show the configuration of the piezometric surface of the lower aquifer in April 1959, when water levels were relatively high, and in October 1960, when they were generally low.

#### WATER LEVELS PRIOR TO INTENSIVE PUMPING

Prior to pumping, the water level in the valley-fill deposits of the Dayton area probably ranged from 5 to 20 feet below the land surface. The Mad River valley in the Fairborn area, northeast of the Huffman Dam, is probably hydrologically similar to the Dayton area prior to the beginning of pumping. There the piezometric surface is about 10 feet below the land surface (Walton and Scudder, 1960, pl. 3).

Few water-level records prior to 1942 are available. A hydrograph of the Shaw Field well 105\* of the National Cash Register Co., for the period 1933-40, is shown on pl. 6. The aquifer in the vicinity of this well was already being fairly heavily pumped during the period of record, so this record is not representative of conditions prior to such pumping.

Several wells, now abandoned, completed between 1917 and 1926 at the Moraine City plants of the Frigidaire Division of General Motors Corp., had static levels ranging from 4 to 12 feet below the land surface at the time of drilling. These levels indicate that the piezometric surface prior to the pumping was considerably higher than it is today. In recent years it has ranged from 20 to 40 feet below land surface in this vicinity. This decline is the expected result of continued pumping over a long period of time.

Well Mt-49 (pl. 6) is situated far enough away from heavy pumping not to be directly influenced thereby. Probably, however, its annual summer decline is accentuated by the pumping at Moraine and at West Carrollton. Its record approximates more nearly than any other observation-well record in the Dayton area conditions in a glacial-outwash aquifer not influenced by pumping. The brief record of Mt-53 (pl. 6) also is characteristic of an area not affected by pumping.

#### HYDROGRAPHS OF OBSERVATION WELLS

Piezometric surfaces continually change in response to natural and artificial recharge and discharge. In a humid temperate climate, such as prevails in Ohio, the recharge factor normally dominates from November through April, and the discharge factor usually dominates

\*This well, now abandoned, was numbered according to a system different from that used in the present report.

from May through October. Of course, the norm is not always attained, as examination of the hydrographs (pl. 6) reveals. An abnormally dry year, such as 1954, causes the piezometric surface to drop far more than usual, whereas a year with above-normal precipitation, such as 1957, brings about a greater than normal rise. Over a period of several years, however, these deviations tend to average out. This annual recharge-discharge cycle is the dominant feature of most hydrographs of wells in the Dayton area.

Hydrographs are especially valuable in that they can indicate long-term overdraft from an aquifer. In a heavily pumped aquifer the natural decline during the summer is usually intensified by the superimposing of artificial discharge (pumpage) on the natural discharge. Moreover, peak pumpage, brought about by the use of water for air conditioning and irrigation, usually occurs during the summer, further intensifying the decline. If over a period of several years the water level of a well is lowered each summer more than can be made up by recharge the following winter, water is said to be "mined," and the result is a water deficit which cannot easily be made up.

Records of observation wells in areas of industrial or commercial pumping typically have daily and weekly cycles of fluctuation superimposed on the annual recharge-discharge cycle. Pumping is usually heaviest during the normal working hours on weekdays and is lightest on weekends; therefore, water levels in the observation wells will show a decline during the daytime followed by a recovery at night each weekday, and a greater recovery each weekend.

The hydrographs of 12 observation wells in the Dayton area are presented on plate 6. Of these records five are currently maintained by the Division of Water of the Ohio Department of Natural Resources in cooperation with the U.S. Geological Survey, three were formerly maintained by industries or public water suppliers, and one was formerly maintained by an industry. Only current records and others of several years' duration are presented herein. Complete lists of water-level records in the Dayton area are given by Kaser (1956, p. 91) and by Norris, Cross, and Goldthwait (1948, table 1).

Some features common to most of the Montgomery County hydrographs are here summarized to avoid repetition in the individual discussions of wells. Precipitation appears to run in cycles of feast and famine (pl. 2). During the period of current observation-well records, the years 1947-50 had precipitation well above normal, whereas 1953-56, and particularly 1953-54, had precipitation well below normal. The period 1957-59 was one of above-normal rainfall, and 1960 was deficient. These conditions are reflected in most of the observation-well records. Particularly evident are the small amount



of recharge in 1953 and 1954 and the immediate response of some wells near rivers to the heavy rainfall and resultant floods of 1957, 1958, and 1959.

#### OBSERVATION WELL Mt-1

*Location.*—In Rohrer's Island well field of the city of Dayton, Mad River Township; sec. 18, T. 2, R. 7, lat  $39^{\circ}48'$ , long  $84^{\circ}06'$ , altitude 780 feet above mean sea level.

*Description.*—Unused drilled well of the city of Dayton; diameter 6 inches, depth 57 feet. Sand and gravel aquifer. Measuring point was top of 6-inch casing 4 feet above land-surface datum; observation by automatic recorder from March 1942 to November 1948.

*Remarks.*—This well shows water-level fluctuations in the upper aquifer (Norris, 1959, p. 3-4). The frequent abrupt fluctuations of the water level of this well are due to variations in the distribution of pumping and changes of head in the artificial-recharge pits at Rohrer's Island. Despite the influence of nearby heavy pumping, the water table in the upper aquifer is maintained at a fairly high level. Owing to these artificial controls, this record is not at all representative of water levels in the Dayton area. It is the only record here where artificial factors dominate over the annual recharge-discharge cycle.

#### OBSERVATION WELL Mt-2

*Location.*—Steam-distribution plant (Fourth St. Sta.) of Dayton Power & Light Co., in downtown Dayton, sec. 4, T. 1, R. 7, lat  $39^{\circ}45'$ , long  $84^{\circ}11'$ , altitude 740 feet above mean sea level.

*Description.*—Unused drilled well of Dayton Power & Light Co.; diameter 8 inches, depth 52 feet. Sand and gravel aquifer. Measuring point at floor of shelter 5.68 feet above land-surface datum; observation by recording gage from May 1952 through December 1960.

*Remarks.*—This well is open either in the lower part of the upper aquifer or in the partially confining till-rich zone that separates the upper and lower aquifers. Figure 22 shows, for comparison, the recorded water levels for 1 week from well Mt-2 and from well 22, which is located in the same building but 143 feet deep and screened in the lower aquifer. The record of well 22 was made at a time when the pump was removed for repairs. The record of well Mt-2 indicates the same daily cycle caused by pumping, with recovery on the weekend, but the peaks and troughs are not so pronounced as those on the record of well 22 and are slightly delayed. Furthermore, the water level in Mt-2 is consistently about  $1\frac{1}{2}$  feet higher than that in well 22. Mt-2 shows the general water-table trend in its vicinity; well 22 shows the altitude of the piezometric surface of the lower aquifer.

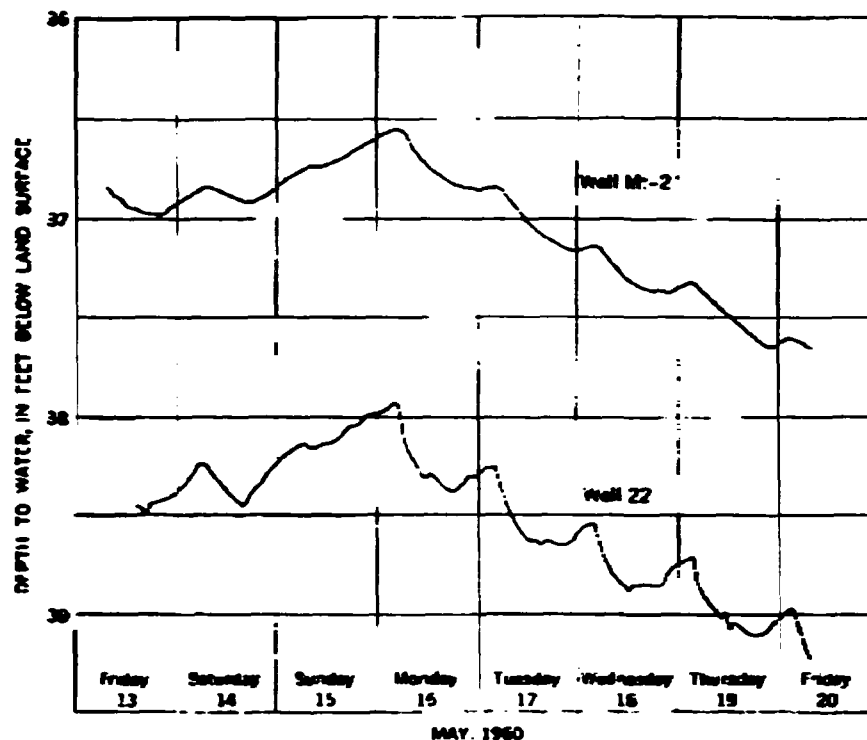


FIGURE 22.—Comparison of recorder charts from wells MI-2 and 23 for the week beginning May 13, 1960.

The increasing declines each summer beginning in 1948 are due to increased pumping of ground water for air conditioning of nearby buildings. In years of normal or above-normal rainfall, winter recovery has been sufficient to offset the previous summer's decline.

#### OBSERVATION WELL MI-2

**Location.**—In park area atop levee on east bank of Miami River at corner of Stewart Street and Patterson Boulevard, Dayton; sec. 2, T. 1, R. 7, lat  $39^{\circ}44'$ , long  $84^{\circ}12'$ , altitude 744 feet above mean sea level.

**Description.**—Drilled test well of the Ohio Department of Highways; diameter 6 inches, depth 80 feet. Sand and gravel aquifer. Measuring point at floor of instrument shelter, 1.2 feet above land-surface datum; observation by recording gage from November 1945 through December 1960.

**Remarks.**—The water level of this well fluctuates in response to the stage of the Miami River and to heavy industrial pumpage (avg 6.5 mgd) at the National Cash Register Co. plant nearby. This well was

originally drilled to a depth of 50 feet; it went dry from August through December 1962 and was then deepened to its present depth of 80 feet. The hydrographs of water-level fluctuations recorded before the well was deepened and of those recorded after it was deepened are generally similar, except that the projected general trend of the second hydrograph lies a few feet below that of the first. The displacement of the two parts of the hydrograph shows that originally the well was open in the upper aquifer, and that deepening the well carried it through the till-rich zone into the lower aquifer, where water levels are generally lower.

#### OBSERVATION WELL Mt-5

*Location.*—Kuhns Bros. Foundry, 1800 McCall Street, Dayton, sec. 5, T. 2 N., R. 6 E., lat  $39^{\circ}44'$ , long  $84^{\circ}12'$ , altitude 744.1 feet above mean sea level.

*Description.*—Unused drilled well; diameter 6 inches, depth 156 feet. Lower sand and gravel aquifer. Measuring point at floor of instrument shelter, 1.2 feet above land-surface datum; observation by recording gage from February 1946 to December 1952.

*Remarks.*—Slight pumpage nearby appears to have little effect on the annual cycle of this well, although it does affect the daily and weekly cycles.

#### OBSERVATION WELL Mt-6

*Location.*—Basement of Municipal Building, Third and Ludlow Streets, Dayton, sec. 4, T. 1, R. 7, lat  $39^{\circ}46'$ , long  $84^{\circ}12'$ , altitude 740 feet above mean sea level.

*Description.*—Unused drilled well of the city of Dayton; diameter 8 inches, depth 60 feet. Sand and gravel aquifer. Measuring point at floor of instrument shelter, 13.0 feet below land-surface datum; observation by periodic measurement from February 1946 to May 1947 and by recording gage from May 1947 through December 1960.

*Remarks.*—Long-term fluctuations are in response to the annual recharge-discharge cycle, with the summer discharge accentuated by nearby pumping for air conditioners. Although this well is of about the same depth as Mt-2, it is highly sensitive to nearby pumping because it is screened in gravel between two fairly widespread till sheets that here constitute the till-rich zone. The well is considered, somewhat arbitrarily, to be open in the upper aquifer.

#### OBSERVATION WELL Mt-49

*Location.*—Barnyard at northeast corner of Farmersville-West Carrollton Road and Baltimore & Ohio Railroad, in village of Whitfield, Jefferson Township, sec. 26, T. 3 N., R. 5 E., lat  $39^{\circ}40'$ , long  $84^{\circ}16'$ , altitude, 715 feet above mean sea level.

*Description.*—Test well drilled on property of Mr. E. F. Stanger; diameter 6 inches, depth 220 feet. Sand and gravel aquifer. Measuring point at floor of instrument shelter, 2.5 feet above land-surface datum; observation by recording gage from November 1947 through December 1960.

*Remarks.*—Mt-49 responds principally to the annual recharge-discharge cycle, and to changes of stage of the Miami River, about half a mile distant. Regional pumping upstream may accentuate the summer discharge, but this is difficult either to prove or to disprove. This well is outside the area of the present investigation but is a good index of ground-water levels in areas not directly affected by pumping.

## OBSERVATION WELL Mt-51 (563)

*Location.*—South side of plant No. 2, Frigidaire Division, General Motors Corp., west side of Springboro Pike (South Broadway) just east of New York Central Railroad in Miami Township, sec. 16, T. 1, R. 6, lat  $39^{\circ}42'$ , long  $84^{\circ}13'$ , altitude 725 feet above mean sea level.

*Description.*—Unused drilled well of the General Motors Corp.; diameter 8 inches, depth 112 feet. Lower sand and gravel aquifer. Measuring point at top of instrument platform, 2.0 feet below land-surface datum. Observation by recording gage May 1953 to June 1960. Maintained by Ohio Division of Water in cooperation with U.S. Geological Survey from May 1953 to April 1955 and designated Mt-51; maintained independently by Frigidaire Division from May 1955 to June 1960 and designated 563.

*Remarks.*—This record is influenced by industrial pumpage of the Frigidaire Division plants, and to a lesser degree by pumpage at the Lamme Road and Dryden Road well fields of the Montgomery County Sanitary Department. Despite its proximity to one of the largest concentrations of pumpage in the Dayton area, no persistent downward trend has been noted in well 563. During the floods of 1957, 1958, and 1959, the effects of recharge from the Miami River, about a mile distant, were very rapid.

## OBSERVATION WELL Mt-52

*Location.*—In Miami River well field of the city of Dayton, 1,250 feet southwest of third turn in Beardshear Road, 900 feet west of Miami River, Harrison Township, sec. 12, T. 2 N., R. 6 E., lat  $39^{\circ}48'$ , long  $84^{\circ}08'$ , altitude 749 feet above mean sea level.

*Description.*—Drilled well, to be put into production as well 1 of the city of Dayton; diameter 26 inches, depth 106 feet. Lower sand and gravel aquifer. Observation by recording gage from March 1957 to July 1960.

*Remarks.*—Mt-53 fluctuated largely in response to changes in stage of the nearby Miami River; there is no pumping within the area of influence of this well. The record of Mt-53 is probably representative of conditions in the valley-fill aquifers of the Dayton area near the major streams prior to heavy pumping.

#### OBSERVATION WELL M-9

*Location.*—In Lamme Road well field of Montgomery County Sanitary Department, Miami Township, sec. 10, T. 1, R. 6, lat  $39^{\circ}42'$ , long  $84^{\circ}13'$ , altitude 743.5 feet above mean sea level.

*Description.*—Drilled test well owned by Montgomery County Sanitary Department; diameter 6 inches, depth 133 feet. Sand and gravel aquifer. Observation by recording gage maintained by Montgomery County Sanitary Department from February 1954 to June 1960.

*Remarks.*—Well M-9 is surrounded by the pumping wells of the Lamme Road well field. The somewhat complicated hydrograph is due to alternation in pumping of several nearby wells at different distances from M-9. Although well M-9 is more than a mile from the Miami River and the wells of the Frigidaire Division lie between it and the river, M-9 responds to floods, though not so rapidly as does well 563.

#### OBSERVATION WELLS 530 AND 531

*Location.*—At Tait Station of the Dayton Power & Light Co., Carillon Boulevard and East River Road, Dayton, sec. 8, T. 1, R. 7, lat  $39^{\circ}43'$ , long  $84^{\circ}13'$ , altitudes 730 feet (530) and 727 feet (531) above mean sea level.

*Description.*—Two test wells of the Dayton Power & Light Co.; both 2 inches in diameter and 120 feet deep. Lower sand and gravel aquifer. Measuring point top of casing, at land surface; observation by weekly measurements by Dayton Power & Light Co. personnel from March 1946 to May 1960.

*Remarks.*—These two wells are affected by pumping at the Tait Station of the Dayton Power & Light Co. and by changes in stage of the Miami River, about 700 feet distant. The abrupt rise in water levels in response to the floods of 1957, 1958, and 1959 is evidence that the hydraulic separation of the upper and lower aquifers is not complete. (See also geologic section D-D'', pl. 3.)

#### PIEZOMETRIC-CONTOUR MAPS

Plates 7 and 8 are generalized contour maps of the piezometric surface of the lower aquifer, based on water-level measurements made in about 60 observation wells in the Dayton area in April 1959 and Octo-

ber 1960. These observation wells had been measured in April 1955 and twice annually in 1958, 1959, and 1960. The April 1959 and October 1960 contour maps were selected for inclusion in the report because they represent generally the highest and lowest water levels during this investigation.

In most places in the Dayton area the outwash deposits are separated into an upper and a lower aquifer by partially confining layers of clay-rich till. Nearly all the industrial supply and much of the municipal supply comes from the lower sand and gravel aquifer, at depths of 100-200 feet below the flood plain of the Miami and Mad Rivers. In areas where the lower aquifer is being heavily pumped, the piezometric surface of this aquifer is several feet lower than the water table of the upper aquifer. Where the lower aquifer is not being heavily pumped, little if any head differential exists.

The piezometric maps represent a compromise with the actual hydrologic conditions as previously described. A literal representation would require separate contour maps of the upper and lower aquifers for each time of measurement. Not enough observation wells tap the upper aquifer, however, to permit construction of such a map for this aquifer. Therefore, the maps accompanying this report are based largely on wells in the lower aquifer, supplemented by records from a few wells in the upper aquifer where no head differential or no separation is believed to exist. The maps are considered to be representative of the static water levels of most wells in the Dayton area. Streams are not treated as recharge boundaries owing to the almost complete isolation of the lower aquifer from the principal streams of the area. The bedrock walls of the Miami and Mad River valleys are arbitrarily selected as the limits of the contoured area.

The general configuration of both maps is the same. The piezometric surface of the lower aquifer in the part of the Dayton area affected by pumping ranges in depth from 20 to 50 feet below the land surface. In parts of the area not affected by pumping it is usually at a depth of less than 20 feet. Four major cones of depression are evident on both piezometric maps. One cone is at the Rohrer's Island well field of the city of Dayton, in the eastern part of the East district. The second and largest cone in the Dayton area includes the Central and South Park districts, the eastern part of the West district, and the northernmost part of the Moraine district. It reaches its lowest point in the wellfield of the National Cash Register Co., in the South Park district. The third cone is at the Dayton Tire & Rubber Co. plant along Wolf Creek in the West district. The fourth cone, in the Moraine district, centers around the Montgomery Country Sanitary

Department well fields and the plants of the Frigidaire Division, General Motors Corp.

Water levels in October 1960 (pl. 8) were lower throughout the area than they were in April 1959 (pl. 7). The change was far from uniform, however. It was greatest in the four areas directly affected by heavy pumping and was least in the areas not so affected. In the four heavily pumped areas the difference in altitudes ranged from 7 to 28 feet and averaged about 15 feet. In the areas unaffected by pumping the range was 1-4 feet. The maximum lowering occurred at the Rohrer's Island well field, where the piezometric surface declined more than 20 feet from April 1959 to October 1960. The minimum lowering of 1-4 feet occurred in north Dayton.

#### CHEMICAL QUALITY OF SURFACE AND GROUND WATERS

The utility of water is determined as much by its chemical quality as by its availability and quantity. Natural water from all sources contains varying quantities of dissolved solids, some of which may be objectionable or may even render the water unsatisfactory for certain uses. A knowledge of the concentrations of these constituents is therefore essential in any ground-water study.

Western Ohio is underlain mostly by carbonate-rich materials. The bedrock consists chiefly of limestone and dolomite, from which the surficial deposits were largely derived. Naturally occurring water tends to reflect its chemical environment, and both ground and surface waters in the Dayton area contain a relatively high proportion of calcium and bicarbonate.

In the present investigation, 44 samples of water from representative wells in the glacial-outwash aquifers of the Dayton area were collected and analyzed; table 8 summarizes the results of these analyses.

Table 9 records analyses of six miscellaneous surface-water samples from the Dayton area and environs. Lamar and Schroeder (1951) summarized the results of a regular surface-water-sampling program carried on during the period 1946-48 and reported on the quality of surface water in more detail than is feasible here.

#### CONSTITUENTS AND PROPERTIES OF NATURAL WATER

The ground-water samples were analyzed for the following: Silica, iron, manganese, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids, hardness, specific conductance, pH, and color (table 8). The surface-water samples were analyzed for all the aforementioned constituents and properties except manganese (table 9). The source of these constituents, the

TABLE 3.—Chemical analyses of ground-water samples from the Dayton area, Ohio

(Results are in parts per million except as indicated)

Well	Owner	Depth (ft.)	Date of collection of sample	Temperature (°F.)	Total solids (ppm)	Iron (ppm)	Manganese (ppm)	Calcium (ppm)	Magnesium (ppm)	Sodium (ppm)	Potassium (ppm)	Ammonia (ppm)	Sulfate (ppm)	Chloride (ppm)	Fluoride (ppm)	Nitrate (ppm)	Dissolved solids (ppm) as CaCO <sub>3</sub>	Hardness (ppm) as CaCO <sub>3</sub>	Specific conductance (micro-mhos/cm at 25°C)	pH	Notes
6	Mills Twp., Burden Co.	80-85	11-28-27	58	15	0.11	0.07	35	25	35	2.2	15	35	35	0.4	4.3	65	65	720	7.5	
14	Dayton Power & Light Co., 2nd St. Sta.	145	4-15-28	58	15	2.0	.15	110	45	35	2.7	25	110	65	.6	.6	217	217	685	7.6	
22	Dayton Power & Light Co., 4th St. Sta.	103	4-15-28	58	14	.05	.25	35	25	11	1.0	25	75	35	.4	.0	95	225	711	7.4	
28	Dayton Power & Light Co., Leaseworth St. Sta.	165	6-15-27	57	17	.05	.15	104	41	14	1.5	275	165	35	.3	2.2	221	225	770	7.2	
31	John Finkbeiner Div., General Motors Corp.	144	11-7-27	58	16	.6	.35	85	35	19	1.0	250	51	24	.4	.3	175	225	755	7.4	
76	Turn-Kumler Co.	135	9-12-17	58	14								35	15	.3	2.0	211	215	685	7.6	
77	Reynolds & Co.	135	9-12-17	58	13								71	15	.3	.7	211	215	685	7.7	
119	Yonke Packing Co.	85	7-15-17	58	15	0.15	0.25	115	25	15	1.5	25	115	35	.5	0.5	215	215	685	7.6	
122	Marley Electric Co.	85	7-15-17	58	15	0.15	0.25	115	25	15	1.5	25	115	35	.5	0.5	215	215	685	7.3	
211	Chrysler Airtemp Sales Co.	85	7-15-17	58	15	0.15	0.25	115	25	15	1.5	25	115	35	.5	0.5	215	215	685	7.3	
216	Dayton Hunt Street Co.	85	12-12-17	57	10	.05	.25	35	25	15	0.4	215	35	24	.5	20.0	35	225	725	7.8	
217	do	141	12-12-17	58	15	.05	.25	115	25	15	1.5	25	115	35	.5	.5	215	215	685	7.6	
220	Acme Paper Co.	125	12-12-17	58	15	.05	.25	115	25	15	1.5	25	115	35	.5	.5	215	215	685	7.6	
221	Dayton Machine Co.	125	12-12-17	58	15	.05	.25	115	25	15	1.5	25	115	35	.5	.5	215	215	685	7.6	
222	Dayton Machine Co.	125	12-12-17	58	15	.05	.25	115	25	15	1.5	25	115	35	.5	.5	215	215	685	7.6	
407	National Cash Register Co.	147	1-10-18	58	15	.05	.25	115	25	15	0.4	215	35	24	.5	1.1	335	225	725	7.5	
410	do	155	1-10-18	58	15	.05	.25	115	25	15	0.4	215	35	24	.5	.5	215	215	685	7.5	
412	do	155	1-10-18	58	15	.05	.25	115	25	15	0.4	215	35	24	.5	.5	215	215	685	7.5	
420	City of Dayton, Miami View Golf Course.	155	1-10-18	58	15	.05	.25	115	25	15	0.4	215	35	24	.5	.5	215	215	685	7.4	



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518.	Crume Brick Co.	120	4-10-37	16	1.9	.00	83	85	7.8	1.0	340	33	11	.8	.1	377	351	40	640	7.3	4
519.	H. G. Darroch.	88	4-10-37	27	3.8	.00	84	45	8.2	1.3	446	21	1.2	1.3	.1	388	378	10	678	7.4	3
520.	Dayton Power & Light Co.	28	6-12-36	60	.25	.18	111	26	23	2.2	462	72	22	.2	10.0	512	486	63	868	7.2	3
521.	Moraine Substa. Dayton Power & Light Co., Frank M. Tait Bldg.	65	6-12-36	8.8	.20	.16	77	20	13	2.0	267	74	19	.8	1.6	377	311	76	624	7.6	3
522.	do	65	6-12-36	56	.82	.03	90	33	11	2.8	262	94	14	.3	2.1	410	360	64	662	7.4	3
523.	do	79	6-16-35	39	.31	.00	88	38	38	4.0	286	165	99	.4	4.7	480	388	189	813	7.4	3
524.	do	108	6-17-37	108	1.2	.10	91	36	18	1.8	328	85	24	.8	.1	462	373	108	705	7.6	3
541.	Frigidaire Div., General Motors Corp.	111	12-12-37	86	.86	.00	82	38	12	1.8	368	98	14	.2	2.3	514	375	66	726	7.3	1
555.	do	131	12-12-37	84	1.5	.02	79	34	18	1.8	348	53	29	.5	.00	386	337	32	666	7.4	1
559.	do	123	4-22-35	18	2.8	.14	122	45	28	2.2	406	169	19	.1	6.8	651	490	157	832	7.7	1
566.	M. G. Snyder & Son Co.	109	4-10-37	55	.03	.00	90	36	1.2	1.1	384	51	16	.8	4.5	411	381	68	684	7.2	1
588.	Frank M. Tait City of Dayton	172	4-9-37	67	.86	.00	88	35	8.8	1.7	368	28	18	.4	5.9	388	356	63	690	7.2	1
C-4.	do	86	11-23-37	28	2.9	.14	104	60	5.2	1.8	486	87	10	.4	.2	677	424	82	745	7.8	1
C-15.	do	86	11-23-37	66	.45	.02	90	85	12	2.3	346	88	17	.6	5.2	431	346	88	662	7.4	1
C-23.	do	11	20-37	63	9.8	.04	87	32	10	2.1	280	63	18	.4	4.1	628	345	111	662	7.7	1
C-44.	do	11	22-39	60	9.8	.08	83	26	9.1	1.8	286	71	16	.3	6.4	374	327	32	624	7.6	1
C-46.	do	122	4-22-39	13	.06	.00	102	88	16	4.8	344	97	28	.4	21.0	484	468	121	798	7.2	1
C-47.	do	122	4-15-35	37.5	.03	.00	104	38	32	2.2	330	100	68	.6	8.1	523	484	112	870	7.8	1
T-1.	City of Dayton, Miami River well field	189	4-11-35	16	2.0	.11	74	35	5.3	1.3	740	37	4.5	.8	2.6	841	329	50	866	7.8	1
O-1.	City of Oakwood	86	4-16-36	88	.02	.00	118	43	31	1.8	423	85	47	.2	2.8	607	472	118	976	7.4	4
M-2.	Montgomery County Sanitary Dept.	260	4-16-38	84.8	.08	.02	91	34	1.1	1.1	362	49	10	.2	4.2	481	367	54	676	7.2	4
M-4.	do	166	4-10-37	58	.01	.12	87	32	5.2	.9	360	48	19	.5	0.1	388	349	62	635	7.3	1
M-6.	do	180	3-19-39	60	.02	.02	83	36	1.0	.9	364	48	13	.1	4.8	604	381	66	701	7.6	1
M-8.	do	157	3-19-39	54	.08	.18	76	29	3.6	.7	288	53	12	.2	.7	345	267	62	574	7.5	1
M-10.	do	247	4-16-38	54	.64	.08	80	29	5.2	.8	270	48	13	.5	.1	274	289	68	608	7.8	4

TABLE 9.—Chemical analyses of surface-water samples from the Dayton area, Ohio

[Results are in parts per million, except as indicated]

Source	Date of collection of sample	Mean depth, ft.	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sulfate (SO <sub>4</sub> )	Phosphate (P)	Bicarbonate (HCO <sub>3</sub> )	Sulfide (S)	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved solids (mg/l.)	Hardness as CaCO <sub>3</sub>		Alkalinity as CaCO <sub>3</sub>	pH	Specific conductance (micro-mhos/cm)
															Calcium	Magnesium			
Miami River at Taylorville..	8-10-46	285	8.8	0	79	19	7.6		229					179	229	79		7.7	80000000
Do.	9-10-46	121	1.0		71	20	10		229					179	229	79		7.8	70000000
Do.	9-20-46	121	7.8		76	20	10		229					179	229	79		7.8	70000000
Do.	4-1-47	121	8.8		76	20	10		229					179	229	79		7.8	70000000
Miami River at Hamilton..	4-1-47	2.1	8.4		80	20	10		229					179	229	79		7.8	70000000
Do.	9-10-46	121	4.0		80	20	10		229					179	229	79		7.8	70000000
Do.	9-10-46	121	4.0		80	20	10		229					179	229	79		7.8	70000000
Well (flow) near Hamilton	10-11-46	1,000	8.8		80	20	10		229					179	229	79		7.4	70000000
Point	8-20-47	121	4.4		80	20	10		229					179	229	79		7.8	70000000
Sandusky River at Englewood	8-14-46	410	7.8	11	84	20	10		229					179	229	79		7.7	70000000
Do.	9-10-46	14	1.2		84	20	10		229					179	229	79		7.8	70000000
Do.	10-10-46	175	8.0		84	20	10		229					179	229	79		7.8	70000000
Mad River near Dayton..	8-14-46	942	7.8		84	20	10		229					179	229	79		7.8	70000000
Do.	9-10-46	121	8.4		84	20	10		229					179	229	79		7.8	70000000
Do.	10-11-46	121	8.4		84	20	10		229					179	229	79		7.8	70000000
Do.	9-10-46	121	7.4		84	20	10		229					179	229	79		7.8	70000000
Do.	9-10-46	121	7.4		84	20	10		229					179	229	79		7.8	70000000
Do.	9-10-46	121	6.7		84	20	10		229					179	229	79		7.8	70000000

† Water discharge records for October 1946 are current-meter measurements or computed provisional discharge at time of sampling.

‡ Current-meter measurement at time of sampling.

§ Includes equivalent of 8 parts of carbonate (CO<sub>3</sub>).¶ Includes equivalent of 8 parts of carbonate (CO<sub>3</sub>).‡ Includes equivalent of 17 parts of carbonate (CO<sub>3</sub>).

factors accounting for the properties, and the significance of both with respect to the various uses of water are discussed briefly. Hem (1959) presented a fuller discussion in his study of the geochemistry of natural water.

#### SILICA ( $\text{SiO}_2$ )

Silicon is second to oxygen as the most abundant element in the earth's crust. It occurs in nature in the form of the silicate radical ( $\text{SiO}_4$ ) or as silica ( $\text{SiO}_2$ ). Silica has a low solubility, but all natural water contains small quantities of it. The silica content of ground-water samples from the Dayton area ranges from 8.8 to 18 ppm (parts per million) and averages 14 ppm. It can cause the formation of a hard scale in boilers, particularly in high-pressure boilers.

#### IRON (Fe)

Iron is present in all rocks and consequently is a constituent of nearly all natural water. Iron concentration in the ground-water samples in the Dayton area ranges from 0.00 to 3.5 ppm and averages 0.66 ppm. A concentration of about 0.3 ppm or greater stains enamel, porcelain, and clothing. Iron concentration in excess of about 0.5 ppm gives water an unpleasant taste but causes no deleterious physiological effects.

The presence of so-called "iron bacteria" in wells and water-transmission lines creates a special problem. Iron bacteria are not true bacteria but are living organisms often found in natural water. Speller (1935, p. 187-188) reported that they depend upon iron for existence and thrive in slightly acid water containing 2 ppm or more iron. *Crenothrix* is probably the most common of the several iron bacteria known. Metallic and nonmetallic materials that carry water containing iron bacteria become coated by nodules of ferric hydroxide or by a slimy scum impregnated with ferric hydroxide. The water may become colored red, and its rate of flow may be affected by the activity of these organisms. They are responsible for one of the major water-treatment problems in the Dayton area but can be checked by certain methods. The Dayton Power & Light Co. chlorinates its water to kill the bacteria and adds a polyphosphate compound to keep the iron in solution.

#### MANGANESE (Mn)

The concentration of manganese in water is generally less than that of iron; however, the effects of the two constituents are similar. Of the 44 ground-water samples analyzed, 30 have a measurable concentration of manganese, ranging from 0.01 to 0.50 ppm and averaging 0.08 ppm. The manganese concentration of 18 samples equals or

exceeds the U.S. Public Health Service (1962) recommended limit of 0.05 ppm.

#### CALCIUM (Ca)

Calcium is one of the major constituents of natural water in a limestone terrane such as that in which the Dayton area is situated. Concentrations of calcium in the ground-water samples analyzed range from 60 to 131 ppm and average 95 ppm. Calcium and magnesium are the principal causes of water hardness; their effects are discussed under the heading "Hardness."

#### MAGNESIUM (Mg)

Dolomitic rock or unconsolidated materials derived therefrom are the principal source of magnesium. Concentrations of magnesium in the ground-water samples from the Dayton area range from 29 to 46 ppm and average 36 ppm. The effects of magnesium on ground water are discussed under "Hardness."

#### SODIUM (Na) AND POTASSIUM (K)

The alkali metals sodium and potassium are discussed together, as their source and effects are similar. Sodium is generally the more abundant of the two and is more easily dissolved from the source rock. Combined concentrations of the two metals in the ground-water samples analyzed range from 6 to 43 ppm and average 18 ppm. Although relatively low, these concentrations of the alkalis are sufficient to cause undesirable effects in some uses, such as in high-pressure boilers.

#### BICARBONATE ( $\text{HCO}_3$ )

Water which contains carbon dioxide ( $\text{CO}_2$ ) dissolves the carbonates of calcium and magnesium from rock, forming the bicarbonate ( $\text{HCO}_3$ ) ion. In a carbonate-rich terrane, bicarbonate is one of the major constituents of natural water. Concentrations in the ground-water samples analyzed range from 268 to 470 ppm and average 368 ppm. At high temperatures in boilers, the bicarbonate decomposes to yield carbon dioxide, which is corrosive.

#### SULFATE ( $\text{SO}_4$ )

Sulfate in natural water is largely dissolved from gypsum, a highly soluble mineral which occurs in the limestones and dolomites of western Ohio. Concentrations in the ground-water samples analyzed range from 21 to 189 ppm and average 80 ppm. Sulfate causes much of the noncarbonate hardness of water. Sulfate combines with calcium to form hard scale in boilers and in other heat-exchange equipment. The U.S. Public Health Service (1962) recommends that the sulfate content of drinking water not exceed 250 ppm.

## CHLORIDE (Cl)

Chloride is a minor constituent of ground water in the glacial-outwash aquifers of the Dayton area. Concentrations in the ground-water samples analyzed range from 1.3 to 67 ppm and average 23 ppm. All the samples of ground water (table 8) and surface water (table 9) contain less chloride than the 250-ppm limit recommended by the U.S. Public Health Service (1962) for drinking water.

## FLUORIDE (F)

Minute quantities of fluoride are found in most water from limestone terrane. In the analyses of ground water in the Dayton area, the fluoride concentration ranges from 0.1 to 1.8 ppm and averages 0.35 ppm. Protracted use of water having more than 1.5 ppm fluoride can cause mottling of teeth, especially in children (Dean and others, 1942). The U.S. Public Health Service (1962) recommends that the average fluoride concentration should not exceed 0.8-1.7 ppm; the figure depends on the annual average of maximum daily air temperatures.

NITRATE ( $\text{NO}_3$ )

Most of the nitrate occurring in ground water is derived from soil in which legumes are grown and on which animal excrement and nitrate fertilizers have been distributed. The concentrations reported in analyses of the ground-water samples from the Dayton area range from 0.0 to 30 ppm and average 4 ppm. All these analyses are well under the tentative limit of 45 ppm nitrate recommended by the U.S. Public Health Service (1962). The presence of nitrate in excess of this amount in drinking water has been definitely correlated with methemoglobinemia (cyanosis, or "blue baby" disease) in infants (Maxcy, 1960).

The three wells (216, 520, C-47) that yielded 10 ppm or more of nitrate are all located near streams and probably are receiving recharge by infiltration of stream water having a high nitrate content due to pollution. All other reported concentrations of nitrate are below 8 ppm.

## DISSOLVED SOLIDS (RESIDUE AT 180°C)

The determination of dissolved solids is made in laboratories of the U.S. Geological Survey by evaporating a suitable volume of the sample to near dryness on a steam bath and then drying the residue in an oven for 1 hour at 180°C (Hem, 1959, p. 49-50; Rainwater and Thatcher, 1960, p. 220). Concentrations of dissolved solids in ground-water samples from the Dayton area range from 274 to 654 ppm and average 458 ppm. Water having more than 1,000 ppm of dissolved solids is generally considered to be unsatisfactory for most purposes.

The recommended upper limit of dissolved solids in drinking water is 500 ppm (U.S. Public Health Service, 1962). Some specialized industrial applications require a much lower concentration.

#### HARDNESS

For many years water's hardness has been regarded as its soap-consuming property. Soap-consuming water contains cations, chiefly calcium and magnesium, that form insoluble compounds with soap. This traditional concept is not entirely satisfactory, however, because a great many constituents other than those usually considered as contributing to hardness will react with soap. In analyses by the U.S. Geological Survey a standard procedure has been adopted (Hem, 1959, p. 146). Hardness is reported under two classifications: carbonate and noncarbonate. These are approximately equivalent to the traditional terms "temporary hardness" and "permanent hardness." Hardness that is attributable to calcium and magnesium is reported as an equivalent quantity of calcium carbonate ( $\text{CaCO}_3$ ).

Carbonate hardness of the ground-water samples collected in the Dayton area ranges from 269 to 516 ppm and averages 386 ppm; non-carbonate hardness of the same samples ranges from 100 to 169 ppm and averages 86 ppm.

Ground water in the Dayton area is hard by almost any standard. Treatment is necessary for boiler use and is desirable for most other uses. The widespread use of detergents, however, has in many instances eliminated the need for softening water used for laundering. The lime-soda method of treatment is used by the Dayton water system to reduce the carbonate hardness to about 100 ppm. The other public water-supply systems in the area do not soften their water. Most small water-softening installations use the ion-exchange or zeolite method, whereby the calcium and magnesium ions are exchanged for sodium ions.

#### SPECIFIC CONDUCTANCE

The conductance of a solution (its ability to conduct an electrical current) generally is directly related to its dissolved-solids content. Conductance is the reciprocal of resistance and is measured in mhos, the reciprocal of ohms. As the conductance of all natural water is well below 1 mho, it is measured in micromhos ( $\text{mhos} \times 10^6$ ). In water analyses by the U.S. Geological Survey the specific conductance is reported in micromhos at 25°C (Hem, 1959, p. 38).

Although specific conductance is not invariably related to the dissolved-solids content of water, it can be used to estimate such content. In the ground-water samples from the Dayton area, specific conductance ranges from 508 to 969 micromhos and averages 742 micromhos.

The specific conductance of water from glacial-outwash aquifers of the Dayton area generally is 1.5–2 times the dissolved-solids content.

#### **pH**

The pH value (the negative logarithm of the hydrogen-ion concentration) is a measure of the acidity or alkalinity of a solution. A pH of 7.0 denotes a neutral solution, less than 7.0 denotes an acid solution, and more than 7.0 denotes an alkaline solution. The pH of ground-water samples from the Dayton area ranges from 7.2 to 7.8 and is therefore on the alkaline side of the scale.

#### **COLOR**

Color is measured by a platinum-cobalt scale, on which one unit represents the color produced by 1 ppm of platinum. Most color in natural water is due to the presence of organic matter. In the ground-water samples from the Dayton area, color ranges from 1 to 6 color units and averages 3 color units. These values are insignificant for most uses of water and cannot be detected by the unaided eye.

#### **TEMPERATURE**

Temperatures of the ground-water samples from the Dayton area, when collected, ranged from 50° to 64°F and averaged 57.5°F. Temperatures of ground water in the Dayton area generally range from 52° to 56°F. The wider range of temperatures reported is due primarily to recharge by induced infiltration of warmer and colder surface water. Shallow wells that are pumped at a high rate and are near a stream yield water whose temperature usually fluctuates over a wide range seasonally, perhaps as much as from 45° to 75°F. Deep wells, and shallow wells not near a stream, generally yield water of more uniform temperature.

#### **CHEMICAL QUALITY OF SURFACE WATER AND ITS RELATION TO GROUND WATER**

The chemical quality of surface water is far more variable than that of ground water. There are two primary causes for this: (1) large seasonal fluctuation of discharge and attendant concentration or dilution of individual constituents and (2) the variability of contamination by effluent from industries and municipal sewage plants. The records of miscellaneous sampling of the Miami, Mad, and Stillwater Rivers and of Wolf Creek (table 9) illustrate the variation in concentrations.

In general, the surface water sampled in the Dayton area contains less dissolved solids than the ground water sampled. Nitrate is generally higher for the surface-water samples but well below the upper limit of 45 ppm. The values for color and pH likewise are higher

for the surface-water samples, and the temperature of the surface water shows a far wider range than that of the ground water.

The quality of surface water is of special interest in a ground-water investigation because in heavily pumped areas adjacent to a stream most recharge to the aquifer comes from induced infiltration from the stream.

The possibility always exists that polluted stream water may contaminate the aquifer. There is no evidence to date to suggest that any such contamination of the aquifer has taken place.

#### GRAPHIC PRESENTATION OF CHEMICAL-QUALITY DATA

Graphs are useful for presenting a concise summary of water-quality data, for they often clarify the less obvious relationships of the dissolved constituents in water. Several graphic methods of presenting these data have been devised, and their applications were summarized by Ham (1959, p. 164-186).

Two graphic methods were chosen to summarize the data of this investigation. The first (fig. 23) is a nomograph devised by Schoeller (1935) and adapted by R. C. Vorhis of the U.S. Geological Survey. As used here, the maximum, minimum, and average concentrations of the principal constituents of the 44 ground-water samples from the Dayton area are shown. Also plotted, for comparison, are the averages of daily sampling of the Miami and Mad Rivers in 1946 and 1947 (after Lerner and Schroeder, 1951). This diagram is especially useful for conversion of the various constituents from parts per million to equivalents per million.

Figure 24 is a trilinear diagram devised by Piper (1944) for showing the percentage composition of the principal chemical constituents of natural water. The diagram is an equilateral triangle divided into three fields. The lower left and lower right fields are smaller equilateral triangles, and the central field is diamond shaped. Piper's diagram indicates only the relative concentrations of the principal ions. It represents the cations calcium (Ca), magnesium (Mg), and sodium plus potassium (Na + K); and the anions chloride (Cl), carbonate plus bicarbonate ( $\text{CO}_3 + \text{HCO}_3$ ), and sulfate ( $\text{SO}_4$ ). The percentage of each of the cations in equivalents per million is plotted at a point in the left triangular field according to conventional trilinear coordinates; the percentage of each of the three anions is plotted in the right triangular field. The two points for each analysis are projected parallel to the sides of the greater triangle, as shown in the small inset of figure 24, into the central diamond-shaped field. The point in



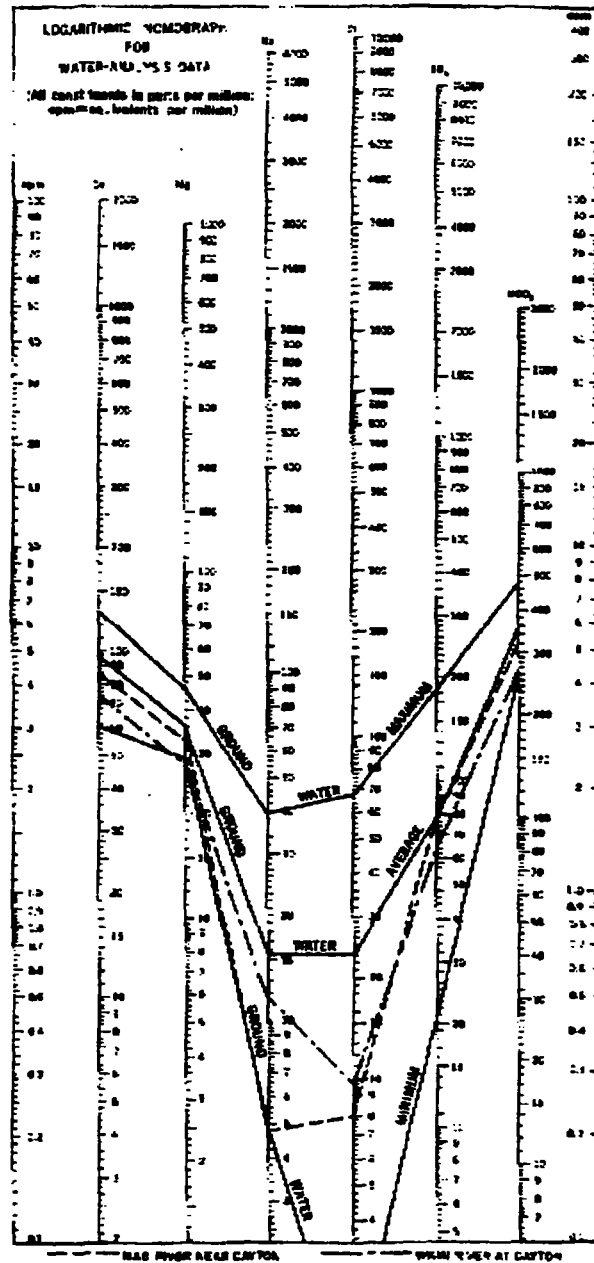


FIGURE 23.—Logarithmic nomograph showing range in concentration of the principal chemical constituents of ground- and surface-water samples from the Dayton area, Ohio.

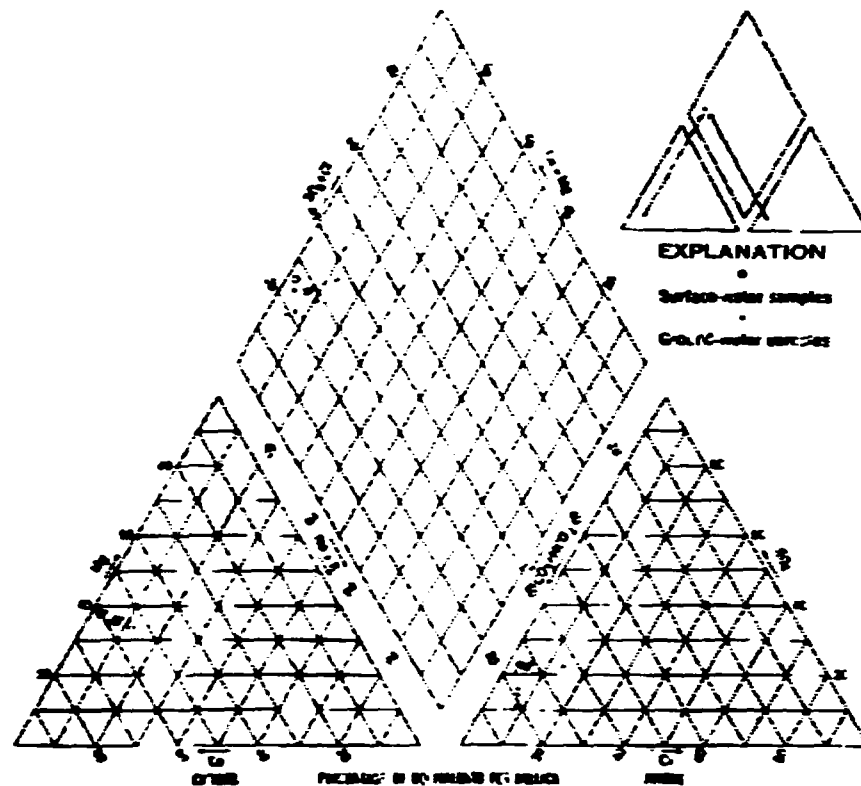


FIGURE 24.—Water-analytic diagram showing relative concentrations of the principal chemical constituents of surface- and ground-water samples from the Dayton area, Ohio. Surface-water samples from Miami River at Dayton and Mad River near Dayton; ground-water samples from wells 14, 311, 418, 503, C-4, C-15, and M-4.

the central field is an index of the chemical composition of the water with respect to the four pairs of ions indicated along the margins of the field.

The analyses of representative ground-water samples from the glacial-outwash aquifers of the Dayton area, plus the averages of analyses of the samples collected daily in 1946-47 from the Miami and Mad Rivers, are plotted in figure 24. It is readily apparent that all these analyses are represented in the same small segment of each of the three fields, indicating that all the waters analyzed are of strikingly similar composition, calcium (Ca) and bicarbonate ( $\text{HCO}_3$ ) being by far the predominant ions. The relative compositions of the ground- and surface-water samples cannot be distinguished on the basis of these diagrams.

## SUMMARY

On the basis of 44 samples analyzed, the ground water in all the valley-fill aquifers of the Dayton area is of remarkably similar chemical composition. Calcium and bicarbonate are the most prevalent constituents and cause an expectedly high hardness. All the samples analyzed are hard by most standards. Iron concentrations of 18 samples exceed the U.S. Public Health Service limit of 0.3 ppm for drinking water. Without treatment, such water would be disagreeable to the taste. Many samples contain enough iron to allow the growth of *Oreothrix* bacteria, resulting in a major treatment problem. All the samples analyzed are chemically satisfactory for drinking. The water requires treatment, however, for many industrial applications.

## FUTURE GROUND-WATER NEEDS

Estimating future ground-water needs is at best a difficult undertaking, and the results are probably arrived at with more qualifications and more uncertainty than forecasts of most other human needs. Public officials and informed private observers alike anticipate a large increase in water use in the years ahead, resulting from several socioeconomic factors, all of which will affect the Dayton area in varying degree. First there is the natural growth in population. In recent years the rate of population growth has been relatively high, and it will probably continue at a high rate in the foreseeable future. Second, the per capita use of water for domestic purposes has increased even faster than has the population, as automatic washers, showers, and other water-using equipment and practices have become more widespread. The per capita rate of increase in domestic use probably will level off, however, as there appears to be a reasonable limit to the amount of water needed for washing, lawn sprinkling, and other home or personal requirements.

The third most important consideration affecting the use of water in the Dayton area is that of industrial water requirements. Generally, the rate of water use by industry has kept pace with or exceeded the increase in industrial output. However, water-saving methods have been instituted by some plants, and ways have been found to reduce the amount of water used in certain processes. Also, in some instances, water that formerly reached the plant effluent after being used only once is recirculated and used over again, perhaps many times. On the other hand, some plants, especially those making synthetic products and chemicals, now use raw materials of lower grade than formerly and require much more water than they did in the past (Piper, 1953, p. 5). There are no large chemical or synthetic plants

at Dayton, and probably no significant changes in water use relative to plant output have occurred in recent years.

Some plants, for example the Frigidaire Division plant at Moraine City, have begun returning water to the ground on a small scale and there is every likelihood that water-saving methods, reusing of water, and returning of water to the ground will be practiced increasingly by Dayton industries in future years. Despite these conservation measures, however, there is certain to be a large increase in the draft on the aquifers as population and industrial output continue to grow.

The increase in industrial use of water will be much greater than anticipated if large new plants are built at Dayton, or if new products whose manufacture requires additional use of water are developed. Much choice land is still available for industrial expansion. The pool of skilled labor, excellent transportation facilities, and a generally favorable climate for industry make it likely that many new plants will be built here in the next two or three decades. The cost of water may decrease and ultimately limit the rate of any further industrial growth.

In his report on the nationwide water situation, Piper (1953, p. 1) wrote:

*In the half century ended with 1939, our National population about doubled but also our per capita withdrawals of water about doubled—roughly from 600 to 1,200 gallons per day. Thus, our total withdrawal increased about fourfold.*

*In inland areas, the unconsumed part of municipal and industrial withdrawals commonly is returned to streams or lakes and so may be reused downstream, perhaps several times. However, these returned waters generally are polluted by organic matter, acids and chemicals, oils, and other wastes—at some places they are grossly polluted. Also, their temperatures may be substantially higher than that of the original source of water. Thus, unless the flow of the receiving stream . . . is sufficiently large for effective dilution, only limited reuse may be possible.*

Piper (1953, p. 6) estimated the Nation's 1975 water requirements by projecting water-use figures for 1950 approximately 25 years into the future. He wrote:

*This estimate indeed gives us pause. It foresees a doubled water requirement only 25 years hence; the rate of percentage increase would be the same as that we have experienced in the last half-century. It foresees an industrial water requirement two and a half or three times that of the present: the projection is not discordant with recent trends.*

*What is the end-point water requirement? A reasoned answer seems more remote with every year that passes.*

Piper's estimate of a doubling in water use in the 25-year period 1950-75 applies to both surface water and ground water; however, it is not inconsistent with the increase in ground-water withdrawals in

the Dayton area in recent years. In 1950, ground-water pumpage in the Dayton area was about 50 mgd; in 1960, it was about 90 mgd. The tremendous growth of water use predicted by Piper appears to have begun somewhat before 1950 in the Dayton area.

Dr. Jerome P. Pichard of the Urban Land Institute, a private research organization, estimated (The Dayton Daily News, Nov. 18, 1959) that the population of the Dayton metropolitan area, which includes Montgomery and Greene Counties, will be 908,000 in 1980 and 1,343,000 in the year 2000. In 1960 the population of the area was 631,722. Dr. Pichard believes that by the year 2000, Dayton will be one of the major centers in the Great Lakes area, along with Columbus, Indianapolis, Akron, and Louisville.

Not all this million-plus population of the year 2000 will be served by the Dayton and the Montgomery County water systems, but a doubling of the present number of domestic customers served by these systems would seem not unlikely by that time.

Thus, if the per capita use of water for domestic needs continues to increase, at least moderately, in the next several years and if Piper's prediction that the increase in future industrial water requirements will be substantially greater than the increase in the use of water for other purposes is borne out, then estimates of the overall demand for ground water in the Dayton area are impressive indeed. By 1975, only about 15 years hence, ground-water demand will have risen from the 1958 figure of 110 mgd to at least 150 mgd. By the year 2000 no less than 210 mgd will be withdrawn from the valley-fill deposits in the Dayton area. These estimates are probably conservative and take into account the effects of water-conservation measures which probably will become widespread in the next several years. What the demand for water will be a few decades after 2000, say by the middle of the 21st century, cannot even be guessed with reasonable confidence. Of more immediate concern is whether Dayton's water needs in the next 40 years can be met at reasonable cost.

#### CONCLUSIONS

The Dayton area is richly endowed with ground-water resources. This is attested to by the fact that its pumpage of approximately 110 mgd in 1958 represented about one-fourth of the ground water used in Ohio. The thick and extensive sand and gravel aquifers in the valleys of the Miami and Mad Rivers are recharged by the streams which flow over them and yield ground water in quantities that are limited chiefly by the regimen of streamflow and the rate at which water can infiltrate through the streambeds.

Ground-water withdrawals can be materially increased in the Dayton area. An estimated 200 mgd can be obtained simply by continuing the present methods and geographical pattern of development, even though much of the increased pumpage would be from areas already yielding large supplies. The estimate would be higher, perhaps as much as 225 mgd, if most of the new wells that will be needed in the future could be drilled in presently undeveloped or only moderately developed areas. Such wells should be located close to the source streams and should tap the more permeable parts of the aquifers, preferably where there are no interbedded deposits of till to retard the downward movement of water to the well screens.

New wells will not all be drilled in favorable areas, however, as much land has been, or will be, preempted for uses other than water-supply development. Not all industrial plants are located where geologic and hydrologic factors are most favorable for well development. We can conclude, therefore, that ground-water resources will probably never be developed to the maximum extent possible.

Large though the presently undeveloped ground-water resource may seem, the total quantity of water available is brought into sober perspective by the steeply climbing rate of ground-water demand, which indicates a need for 150 mgd by 1975 and for as much as 310 mgd by the year 2000. This means that unless natural conditions are altered—that is, unless the rate of stream infiltration to the underlying aquifers is artificially increased—the Dayton area could experience a general shortage of ground water in less than 40 years. Widespread shortages are not inevitable, however, as economical methods will no doubt be found to increase the rate of replenishment to the principal aquifers. But such methods are not yet at hand, nor is there promise that they will be developed and applied soon enough to prevent the occurrence of local ground-water shortages.

Dayton's ground-water situation, which will dominate plans for additional water-supply development in the near future, is critical because much of the additional ground water needed in the next few years will of necessity be pumped in hydrologically poor areas, or in areas already extensively developed. The result will be an increasing incidence of acute local water shortages which may, unless a comprehensive plan is evolved, force adoption of piecemeal remedial methods and conservation measures that are likely to be both costly and relatively ineffective. Nowhere is this situation better illustrated than in the central and southern parts of Dayton, where ground-water development generally has reached its practical limits and locally has exceeded these limits.

In this area the Miami River traverses what can be called the industrial and commercial heartland of Dayton. From the confluence of

the Mad and Miami Rivers near the Delco and Frigidaire Division plants, the Miami River winds southward through the downtown district with its scores of office buildings, hotels, and department stores, most of which pump large quantities of water for air conditioners; it flows past large industrial plants in the southern part of Dayton, including those of the Delco-Moraine Division and the vast complex of the National Cash Register Co.; thence it winds past the lagoons and beautifully landscaped terrain of National Cash Register's Old River Park, in the bend of a cutoff meander, past nearby Carillon Park with its tower of bells, to leave Dayton in a broad, sweeping meander on which is situated the large Tait Generating Station of the Dayton Power & Light Co.

Ground-water pumpage in this vital area is about 30 mgd, and it has been increasing from the time of earliest records. The hydrographs of observation wells Mt-2, Mt-3, and Mt-6 (pl. 2) show that ground-water levels have generally declined since about 1942, when the record began. The long-term decline has been moderate but persistent. In 1960, an unusually dry year, ground-water levels in wells Mt-2 and Mt-6 were the lowest of record, 2-5 feet lower than in the much publicized drought period of 1938-54.

Although of ominous future portent, the lowering of ground-water levels has not yet caused general concern. Moreover, given a long period of normal streamflow and no more than the expected rate of increase in water use, perhaps a decade or two will pass before low ground-water levels force a general reduction in pumpage. During years of abnormally high streamflow ground-water levels will recover somewhat, as they did in 1957, 1958, and early 1959.

However, as the use of ground water continues to grow in Dayton and the ground-water levels become progressively lower, each drought will produce increasingly severe demands on the reservoirs, hastening the time when acute water shortages or remedial measures become inevitable.

There is little doubt, therefore, that if the growth of Dayton in the next few decades is not to be retarded by rising water costs, ways must be found to use the ground-water reservoirs at their optimum perennial yield. Streamflow may have to be regulated and manipulated to take advantage of the increased rates of infiltration that are associated with relatively high flows. Methods of maintaining higher rates of stream infiltration will have to be developed. These may include dredging or harrowing of the bottom materials in some areas, or diversion of flow into specially prepared recharge ponds in other areas—as is done, for example, at Rohrer's Island. Stream pollution, a matter that has not been explored in this investigation, will

become of greater concern with each passing year, as a progressively higher percentage of the streamflow is diverted into the underlying aquifers. Not only will pollution abatement be necessary to avoid contamination of wells closest to the source of such pollution, but also a reduction in the amount of chemical and organic wastes may be required to maintain high permeability of the channel bottom. There is evidence that the "bottom seal" that retards stream infiltration in parts of the Miami River channel is composed partly of organic wastes which act principally as a binding or cementing agent in forming a nearly impermeable deposit. Finally, conservation measures will have to be practiced on a large scale. These will include the reusing of water, the returning of water to the ground, and avoidance of local overdevelopment of aquifers.

All this implies that the cost of water in the Dayton area will inevitably go up. This is certainly true, but the cost need not rise to prohibitive levels if methods for the proper management of the ground-water resources are instituted now. With respect to the matter of cost, moreover, water generally will cost more in the future, and the Dayton area will merely be in competition with other areas where large supplies of water are available. Piper (1953, p. 6) wrote: "Thus far, availability of water has been a minor factor in the location of most industries, but [here he quotes Paley and others (1952, v. 5, p. 86)] \* \* \* 'by 1973 water supply may be the most important factor affecting industrial location.' This seems to imply that industry will go to the water. But the distribution and marketing of industrial products is through a pattern of transportation routes and commercial centers long since crystallized."

Piper's observation gives pause to some statements that have been made to the effect that "Dayton has no water problem, as areas can be found within a few miles of present centers of pumping where the aquifers are virtually undeveloped." There are such areas, of course; moreover, some new industries will be attracted to these undeveloped areas, and wells will be drilled in other such areas and the water piped to where it is needed. That these things will have a major effect in mitigating or delaying water shortages in the Dayton area is not to be denied. However, Dayton and its immediate environs, with its well-established power, transportation, and communication facilities, will continue to hold more attraction for most industrial and commercial enterprises than relatively undeveloped areas many miles from the main hub of business activity. Dayton certainly is destined for more industry, and that industry will need water—water from the same sources and from wells in the same general areas from whence are supplied the present industrial and municipal requirements.



Special studies and the continuing collection of hydrologic data will insure proper water management and effective conservation measures. The studies should be directed specifically towards determining more about the mechanics of stream infiltration. Recharge rates should be accurately determined over a wide range of stream discharge, and the relationship between various rates of recharge and specific flows in the streams, sediment load, and other factors should be established. Areas most favorable for high rates of stream infiltration should be closely defined, and the effects on infiltration of any differences that might exist from place to place in the character of the sediments that make up the bottom of the channels should be determined. These facts are requisite to the design and proper management of structures that eventually may be deemed necessary to control and regulate streamflow for the purpose of increasing the rate of infiltration, or to determine the best places and methods for dredging or harrowing the streambed. They are likewise needed in the selection of areas for future ground-water development, and for the instituting of proper water-conservation measures. Special studies of the type needed would involve initially the installation of numerous observation wells in the upper aquifer, establishment of one or more additional gaging stations, and a program of water-quality and suspended-sediment study. Techniques and methods of interpretation will of necessity be evolved from the character of the data that are collected.

Additional geologic data also should be collected in the Dayton area if the best use is to be made of detailed knowledge that should become available on the mechanics of stream infiltration. Despite the large number of drillers' records of wells in the Dayton area, much still needs to be learned of the precise character of the aquifers and especially of the extent, continuity, and hydraulic properties of the till-rich zone. Additional electric logs and depth-to-bedrock data would be especially useful to the geologist.

Although generally not a limiting factor in the availability of ground water, the hydraulic properties of the till-rich zone are locally considered in setting pumping rates, and determination of the effectiveness of artificial recharging operations will depend on knowledge of these properties. For example, the till-rich zone controls the amount of water available from the lower aquifer at Rohrer's Island, and it probably will be a determining factor in the selection of recharging methods to be used at the new municipal well field in the Miami River Valley north of Dayton. Therefore, future test drilling and pumping tests should be conducted in the Dayton area to ascertain the character of the till-rich zone wherever possible.

Proper management of Dayton's ground-water reservoirs must inevitably involve the cooperation and support of business and community leaders. This support must be based on an understanding of the basic hydrologic and geologic factors which are responsible for Dayton's ground-water resources, and the recognition that those resources can no longer be considered "inexhaustible." The success of water management can be assured only if business leaders, public officials, and the general public are kept adequately informed of the status of the ground-water supply by intelligent and unbiased investigations and research, including records of water levels in wells, changes in chemical quality of the ground water, trends in water use, and other pertinent data. Until severe water shortages are experienced, it may not be easy to acquaint people with the need to conserve and wisely use Dayton's ground-water resources; however, an informed public might postpone, or defer indefinitely, acute shortages and destructive competition on the part of water users, which would be damaging to the orderly growth of the Dayton area and to the prosperity of its citizens.

# RECORDS OF WELLS IN THE DAYTON AREA

(For more well data, see pl. 8—"Graphic Logs of Wells in the Dayton Area")

Well: See text for well-numbering system.  
Character of aquifer material: Sand and gravel, except in well 804—lm.  
Geologic horizon of aquifer: Pleistocene.  
Type of well: Drilled, except as shown under "Remarks."

Type of pump: C, centrifugal; J, jet; S, submersible; T, turbine.  
Use: A, air conditioning; D, domestic; Ind, industrial; Irr, irrigation; O, observation;  
P, public supply; R, return; S, sanitary; T, test.

## PRIVATELY OWNED WELLS

Well	Owner	Altitude (ft above sea level)	Date drilled	Depth (ft)	Water level		Yield		Type of pump	Diameter of well (in.)	Use	Remarks
					Depth (ft)	Date	Rate (gpm)	Draw- down (ft)				
Central district												
1	Biltmore Hotel	740	4-51	100			580		T	10	AC	Not currently used.
2	do	742	4-51	60	85.8	4-18-55			T	10	H	
3	Ice Cream Div., Borden Co.	740		130	84.42	5-12-55	600	37	T	12	Ind	
4	Milk Div., Borden Co.	739	3-42	110	31.74	5-4-55	100		T	8	Ind	Do.
5	do	739		90					T	10	Ind	
6	CIO Local 801 Hall	740	4-45	160	28	4-5-56	150	30	T	6	AC	
7	do	745	4-50	61	40.5	11-20-57	120	30	None	6	H	Well not used since 1955.
8	Dayton Coca Cola Bottling Co.	740		173	40	4-5-58	800	23	T	12	Ind	
9	Columbia Theater	746	4-48	88	67	4-5-58	150	5	T	6	AC	
10	Commercial Bldg.	740	1837	130					T	10	AC	Well not used since 1955.
11	do	746	1830	146					T	10	AC	
12	Crystal Laundry	741	1937	28	14.25	5-5-58			T	8	Ind	
13	Dayton Power and Light Co., 3rd St. Sta.	738	1908	193	36.80	2-1-59			T	18	Ind	
14	do	738	7-46	140	40	3-3-55	1,000		T	20	Ind	
15	do	735		130					T	8	T	
16	do	736		100						8	T	
17	do	735		70						8	T	
18	do	739		121						8	T	
19	do	738		153						8	T	
20	do	739		100						8	T	
21	do	739		127						8	T	
22	Dayton Power and Light Co., 4th St. Sta.	740	7-48	143	37.45	5-3-50	80		T	8	Ind	Gravel packed.
23	Dayton Power and Light Co., Long- worth St. Sta.	739.5	8-53	149	41	3-3-55	2,000	6	T	20	Ind	
24	do	734.25	7-40	180	38.8	3-3-55	1,500	2-3	T	16	Ind	
25	do	737.8	1-50	87	36	3-3-54	875	31	None	18	Ind	Abandoned.
26	do	736	4-53	172	38						T	

PRIVATELY OWNED WELLS—Continued

Well	Owner	Altitude ft. above sea level	Date drilled	Water level			Yield		Type of pump	Diam- eter of well (in.)	Use	Remarks
				Depth (ft.)	Depth (ft.)	Depth (ft.)	Rate (gpm)	Draw- down (ft.)				
Central district—Continued												
27	Dorton Power and Light Co., Gas & Electric Div., 15 N. Main St.	708	1910	65	88.4	3-4-55	170		T	8	Ind	
28	Duke Products Div., General Motors Corp.	706	3-16	128					T	8	Ind	
29	do	708	3-16	128					T	8	Ind	
30	do	708	1938	144					T	8	Ind	
31	do	708	7-24	144	28		440	0.75	T	10	Ind	
32	do	708	10-29	152	28	10-29			T	10	Ind	
33	do	708	7-28	151	24	7-28			T	10	Ind	
34	do	708	11-27	152	27	9-27-27			T	10	Ind	
35	do	708	9-27	153					T	10	Ind	
36	Donnan's Inc.	708	4-29				125		T	8	SAC	
37	Elby & Johnston Co.	708	12-13	60	29.66	7-29	200		T	8	AU	
38	do	745	4-41	108	28.11	7-15-55	700	13	T	12	AO	
39	Ed-Mey Bldg.	708	12-19	88	25.90	7-15-55			VM	12		Abandoned
40	Fraser & Neave Co.	708	1917	117			70		T	10	AC	
41	do	740	9-26	125	45	9-26		20	T	10	AC	
42	Frederick Div., General Motors Corp.	708	10-26	108					T	12	AC	
43	do	708	10-26	108	21	7-19-51		20	T	12	AC	
44	do	740	7-24	175	26	7-10-55	1,200	10	T	16	Ind	Fire protection with.
45	Gibbons Metal	708	1928	65					T	10	Ind	
46	do	740	1917	120					T	10	Ind	
47	Goodrich & Lamson, Inc.	745	1928	70	45.26	4-15-55	100		T	8	Ind	
48	Home Svc.	708	7-19	140	28	9-26	200	25	T	10	MAU	
49	Hulman Bldg.	708	1928	120				0	T	10	AO	
50	King (Ice) Restaurant	748	7-28	150	28	6-1-55	200		VM	10	SAC	
51	do	708	1928	78					VM	8	Ind	
52	Kraft Bldg.	745	1928						T	10	MAU	
53	Levy's Theater	708	1917	115			200		T	10	AO	
54	Levy Bldg.	745	1927						T	10	AO	
55	McCoy's & 108 More	745	1927						T	10	AO	
56	Metropolitan Clothing Co.	708	1920	80-80			100		T	10	AO	
57	Miami Metal	708	1914	80			200		T	10	AO	
58	do	708	1914	80	28.15	4-24-55			T	8	AO	
59	Miller Bldg.	708	1928	110			400		T	10	AO	No longer used.
60	do	740	7-26	88			60		T	8	AO	

61	Miami Valley Milk Producers Association	740	1923	128			90		T	6	Ind	
62	do	755	8 80	132	27	8-5-88	360	5	T	10	Ind	
63	Model Laundry	748	1906	70			82		T	8	Ind	
64	Moraine Hotel	748	1920	126					C		Ind	
65	New's Dairy	748		72	58.44	6-27-80				8	Ind	
66	do	748	3-64	177	88	7-84	400	18	T	8	Ind	
67	Ohio Bell Telephone Co.	740	2-41	80			135		T	4	AC	
68	do	740	2-37	111	24	2-20-87	460	18	T	10	AC	
69	do	740	2-39	116	38	3-18-88	900	63	T	10	AC	
70	Ottobahn Press	740	1918	75	32.80	4-22-84	85		T	10	Ind	
71	Rialto Theater	740	1948	80-80			80		T	6	AC	
72	Roadsters-Jarrett-Harman Co.	740	1948	148	62.34	4-21-85	165		T	8	AC	
73	do	740	1944	148					None	8	AC	
74	Miller-Kumler Co.	740	1911	55			305		T	8	SAC	
75	do	740	8-34	108	37.28	3-17-86	1,380		T	12	SAC	
76	do	740	4-80	120			1,000		T	12	SAC	
77	Stearns Bookbinder & Co.	741	10-88	148	38	11-23-87	700	18	T	12	AC	
78	Stanley Drawings, Inc.	740	1913	170	43.40	5-8-88			T	10	Ind	
79	Talbot Bldg.	740	1907						T		Ind	
80	Terminal Cold Storage Co.	740	1935	88	27.82	3-16-84	400		T	8	Ind	
81	do	740	1937	98	31.41	3-18-86	400		T	15	Ind	
82	Third National Bank	740	1934	188			400		T	12	AC	
83	Westminster Church	740		28	14	3-88	175	10	T	8	AC	

## East district

104	Acme Precision Products	780	1941		12.88	6-20-84	250		T	8	Ind	
105	Baltimore & Ohio RR.	780	1924	80	12.21	3-28-85	260	8	T	18	Ind	
106	J. J. Boeckman Co.	784	1944	185			15		T	8	Ind	
107	Van Dyne-Credly, Inc.	749	1980	85			85		T	8	AC	
108	B. G. Davis Co.	749	7-84	87	26	7-88	300	0	T	8	Ind	
109	Dayton Packing Co.	754	1980	82			4.88		J	8	Ind	
110	do	754	7-85	101	17	7-85	20	30	J	8	Ind	
111	Durron Oil, Inc.	760	1920	134	11.34	8-12-85			None	8	Ind	
112	Farm Bureau Co-op Association chemical plant	745	1906	110	19	1983	190		T	10	Ind	
113	do	745	1918	76	14				T	8	Ind	
114	Funks Packing Co.	780	1928	50					None	8	Ind	
115	do	780	3-82	33					None	8	Ind	
116	do	780	3-83	85	26	3-88	150		T	8	Ind	
117	do	780	8-85	80	26	11-23-87			T	8	Ind	
118	Ulobe Laundry	788	1914	80					None	8	Ind	
119	do	788	1916	130	11.88	7-7-85			T	8	Ind	
120	Hewitt Pump Co.	788	1931	87	19.44	3-10-80			None	8	Ind	
121	do	788	1931	83	28.88	8-10-85			None	8	Ind	
122	do	770	1940	130	24.87				None	8	Ind	
123	do	785	12-83	87			300	8.84	T	8	Ind	
124	William Martin	770	1-85	147	32	1-8-88	15		J	8	Ind	
125	Master Electric Co.	772	7-84	88	33	8-88	300		T	10	Ind	

Out of service.  
Abandoned.

No longer used.

Abandoned.

Do.

Not used.  
Abandoned.

Driven, Abandoned.

Abandoned.  
Do.  
Do.

PRIVATELY OWNED WELLS—Continued

Well	Owner	Altitude (ft. above sea level)	Date drilled	Depth (ft.)	Water level		Yield		Type of pump	Diameter of well (in.)	Line	Remarks
					Depth (ft.)	Note	Gallons (gpm)	Feet down (ft.)				
East district—Continued												
126	Morans (Lund) Co.	720	12-26	86	13	12-26-55	10		2	6	Ind	Drilled to 86 ft., casing pulled back to 36 ft.
127	W. B. Scott	688	9-24	101	78	9-17-54	6	1	2	6	Ind	
128	Henry Shultz	720	10-24	73	34	10-24-54			2	6	Ind	
129	Shenold Corp.	720	1941	73					2	6	Ind	
127	Yarnes & Wagner, Inc.	715	10-26	68	46	4-2-57	6		2	6	Ind	
128	White Oliver Dairy	720	1955	73					2	6	Ind	
129	C. L. Wolfe	688	11-54	73	68	11-8-54	20		2	6	Ind	
North district												
204	Arthur Ralston's Sons	770	2-22	68	18	2-28-55	40	1	2	6	Ind	
204	Air City Fuel Co.	720	12-24	15	15	12-4-55	20	3	2	6	Ind	
205	Baltimore & Ohio R.R.	737	4-51	65	30	4-2-55	20		2	6	Ind	
206	do	734		70	18.44	2-28-55			2	6	Ind	
207	Shenold Mining Co.	746	1946	179	15.8	2-12-57			2	12	Ind	Drilled to 179 ft. (270 ft.); casing pulled back to 170 ft.
208	Marquette Oxygen Co.	738	1953	142	34	4-51	200	10	2	10	Ind	Abandoned.
207	do	740	1953	110					2	6	Ind	
208	do	740	1953	220					2	6	Ind	
209	Richard Clappan	740	7-24	75	46	2-11-55	20	1	2	6	Ind	
210	Universal Airtemp Sales Corp.	740	1954	68	23	2-14-55	200	11	2	10	Ind	
211	do	740		68	10.04	2-14-55	1,000		2	10	Ind	
212	do	740	1957	107	10	2-14-55	1,000		2	10	Ind	
213	Dayton Castings Co.	741	8-27	78	12	2-14-57			2	6	Ind	
214	do	741	8-27	78	12	2-14-57			2	6	Ind	
215	Dayton Power & Light Co.	740	9-41	68	18.0	2-14-57	200		2	6	Ind	Neither well used as of 1958. Return well.
216	Dayton Rust Proof Co.	740	1954	68	23	2-14-57	200		2	6	Ind	
217	do	740	8-27	141	26	2-14-57	200		2	6	Ind	
218	East Dayton Tool & Die Co.	741	1956	65	26	2-14-57	200		2	6	Ind	
219	Keunmyung Eisen & Towel Co.	740	1954	68	26				2	6	Ind	
220	Oliver Foundry	740	11-54	70			200		2	6	Ind	
221	do	740	2-27	70			200		2	6	Ind	
222	do	740	1957						2	6	Ind	

243	Golden Age Dayton Corp.	742	6-58	78	10	5-58	800	20	T	12	Ind	Well no longer used.
244	Lincoln Co-op Dairy	742	1940	87	72	9-48	800		T	8	Ind	
245	James Kinn	774	12-48	95	31	12-48	80	0	T	8	Ind	
246	Keystone Sand & Gravel Co.	788	8-43	80	28.28	3-28-48			T	28	Ind	Drilled for use during construction.
247	Mad River Township School	788.24		144	44	4-8-58			Name	8	8	
248	do	788	7-58	122	47	7-31-58			T	8	8	
249	W. C. Martin	754		80					Name	4	8	All water returned to return well.
250	McCook Bowling Co.	741	1941				80		T	8	AT	
251	D. W. Mikosell Co.	742	6-55	78	14	1-16-55	400	10	T	8	Ind	
252	Molen Dairy	788	1930	85			75		T	8	Ind	None.
253	Wm. H. Olson	778	4-54	81					T	8	D	
254	Charles Miller	788	6-55	77	31	6-19-55	28	8	T	8	D	
255	Polish-American Democratic Club	758	6-54	82	8	6-7-54	20	5	T	8	H	None.
256	Franklin Rubber Co.	750	9-45	118	14	9-48	1,000	19	T	10	Ind	
257	Prime Term	745	11-54	79	12.7	11-17-56			T	8	Ind	
258	Mary Radvansky	778	12-58	80	88	12-5-58	15	8	T	8	Ind	None.
259	Shell Oil Co.	788	4-49	83	50	4-23-49	200	15	T	8	Ind	
260	Shenale Refining Co.	788	10-49	81	24	10-4-48	180	10	T	8	Ind	
261	Miss Smart	788	9-54	89	84	9-8-54	15.8	5	T	8	Ind	None.
262	Klein Corp.	745	12-58	75	14.5	12-5-58	180	8	T	8	Ind	
263	T. Dye Products	768	5-57	100	31	5-17-57	20	5	NW	8	Ind	
264	Univis Lens Co.	742	1939	100					T		Ind	None.
265	L. A. Walproun	750		87							Ind	
266	Floyd Walker	750	10-54	87	18	10-4-54	30	8		8	Ind	
267	Mrs. Hehl	750	2-53	86	20						Ind	None.
268	Frank Miller	740	8-58	88	38	8-24-58	8.8	20		5	Ind	
269	Carl Hale	773	1-53	34	16	1-24-53	43			6	Ind	
270	Vergil Evans	773	7-48	41	38	7-27-48	80	1			Ind	

## West district

281	Artina Paper Co.	780	11-41	134					T	12	Ind	Fire protection only.
282	do	740	3-45	140	40.8	3-15-38			T	12	Ind	
283	do	790	3-41	132	47	3-29-45			T	13	Ind	
284	do	740	10-47	123	65	1-15-48			T	15	Ind	Piston. Abandoned.
285	City Printmate Corp.	748	1928	96	30.5		800		T	8	Ind	
286	do	748	1928	98	30	1-50	200		T	8	Ind	
287	Davies Young Soap Co.	744	9-49	120			250		T	10	Ind	Piston. Abandoned.
288	Wolf Crank Soap Co.	700	1918	90			50			4	Ind	
289	do	701		35	18.80	6-14-54			Name	4	Ind	
290	do	701		29	14.38				Name	4	Ind	Not yet used.
291	Dayton Rubber Co.	753	1-44	108			1,000		T	15	Ind	
292	do	753	2-58	134	80	2-5-58	1,000	25	T	10	Ind	Not yet used.
293	do	753	7-47	198	82	7-23-58	2,000	48	T	16	Ind	
294	Dayton Steel Foundry Co.	742	8-54	148	45	8-5-54	1,000	30	T	22	Ind	
295	do	742	1-52	87	30	1-5-52	430		T	18	Ind	Not yet used.
296	Paul's Motor Sales	730	10-53		32.90	6-18-53			Name		Ind	
297	Gran City Ice Cream Co.	782	8-42	137	23.80	4-8-55	200		T	8	Ind	
298	do	743	3-45	130			350		T	10	Ind	

## PRIVATELY OWNED WELLS—Continued

Well	(Owner)	Alt. top of well (ft. above sea level)	Date drilled	Depth (ft.)	Water level		Yield		Type of pump	Dist. from well (ft.)	Use	Remarks
					Depth (ft.)	Rate	Gals. (gpm)	Draw-down (ft.)				

West district—Continued

218	Flann Bros. Dairy	725	1938	100	73.5	1-25-35	100		Hand	0		Not used.
219	do	725	1938	100	73.5	1-25-35	100		Hand	0		
220	do	725	1938	100	73.5	1-25-35	100		Hand	0		
221	Dairy Div., Kroger Co.	725	1938	100	73.5	1-25-35	100		Hand	0		Abandoned.
222	do	725	1938	100	73.5	1-25-35	100		Hand	0		1 in.
223	do	725	1938	100	73.5	1-25-35	100		Hand	0		
224	Kuhns Bros. Foundry	725	1938	100	73.5	1-25-35	100		Hand	0		
225	Kuhns Bros. Foundry	725	1938	100	73.5	1-25-35	100		Hand	0		
226	Kuhns Bros. Foundry	725	1938	100	73.5	1-25-35	100		Hand	0		
227	Lee Brewer Co.	725	1938	100	73.5	1-25-35	100		Hand	0		
228	McCall Corp.	725	1938	100	73.5	1-25-35	100		Hand	0		Discontinued pumping in 1944.
229	do	725	1938	100	73.5	1-25-35	100		Hand	0		
230	do	725	1938	100	73.5	1-25-35	100		Hand	0		
231	do	725	1938	100	73.5	1-25-35	100		Hand	0		
232	do	725	1938	100	73.5	1-25-35	100		Hand	0		
233	do	725	1938	100	73.5	1-25-35	100		Hand	0		
234	Monroe Chemical Co.	725	1938	100	73.5	1-25-35	100		Hand	0		
235	do	725	1938	100	73.5	1-25-35	100		Hand	0		
236	do	725	1938	100	73.5	1-25-35	100		Hand	0		
237	do	725	1938	100	73.5	1-25-35	100		Hand	0		
238	DeLoe-Murphy Div., General Motors Corp.	725	1938	100	73.5	1-25-35	100		Hand	0		
239	do	725	1938	100	73.5	1-25-35	100		Hand	0		
240	do	725	1938	100	73.5	1-25-35	100		Hand	0		Test well here 200 ft. deep.
241	do	725	1938	100	73.5	1-25-35	100		Hand	0		
242	do	725	1938	100	73.5	1-25-35	100		Hand	0		
243	National Foundry & Machine Co.	725	1938	100	73.5	1-25-35	100		Hand	0		
244	do	725	1938	100	73.5	1-25-35	100		Hand	0		
245	Alameda-Worden-White	725	1938	100	73.5	1-25-35	100		Hand	0		Dug. Abandoned.
246	do	725	1938	100	73.5	1-25-35	100		Hand	0		
247	Standard Register Co.	725	1938	100	73.5	1-25-35	100		Hand	0		
248	Standard Register Co.	725	1938	100	73.5	1-25-35	100		Hand	0		
249	Standard Register Co.	725	1938	100	73.5	1-25-35	100		Hand	0		
250	do	725	1938	100	73.5	1-25-35	100		Hand	0		Abandoned.



351	do	740	10-58	70					None	12		Capped, never used.
352	do	740	10-58	140	20.5	9-54	225	70	None	12	Ind	
353	do	740	10-58	167					None	12	R	Never used.
354	do	740	10-58	208					T	10		Not yet used.
355	do	740	10-58	208					None	6	T	
356	do	740	10-58	208					None	6	T	
357	do	740	10-58	208					None	6	T	
358	Sunshine Biscuits, Inc.	741		118	24.75	9-27-48	480	80	T	12	Ind	
359	do	741	4-46	108	21.75	9-27-48	716	80	T	12	Ind	
360	do	741	4-46	118	41		888	11	T	12	Ind	
361	do	741		78	21.75	9-27-48			T	12	Ind	
362	do	741		78	66.12	11-6-57			None	12	O	

## South Park district

401	Holdenborg Cals	740	6-48	78	46	6-48			T	8	R	Abandoned.
402	Miami Malt Bakery	740		110	38	1-16-55			None	6		
403	National Cash Register Co.	743	6-44	144	24.68	9-48	1,200	88	T	18	Ind	
404	do	740	10-53						T		T	
405	do	740	10-53	180							T	
406	do	740	9-41								T	
407	do	740	3-12	147	21.24	9-30	200	41	T	16	Ind	
408	do	724.27	4-30	129	41.37	9-30	1,100	20	T	12	Ind	
409	do	713.75	12-36	98	23.20	9-30	800	16	T	20	Ind	
410	do	723.8	12-36	122	43.82	9-30	800	46	T	12	Ind	
411	do	746	7-37		65	7-37					T	
412	do	746	6-37	57			250	6	T	16	Ind	Not used. Capped.
413	do	728.68	4-37	83	37.88	3-54	450	7	T		Ind	
414	do	786	12-29	70			700	6	T	12	Ind	
415	do	737	6-37	62	74	6-15-37				6	T	
416	do	744	10-11	101							T	
417	do	749	2-49	107						6	T	
418	do	746	3-31	149	44.8		1,000		T	14	Ind	
419	do	753	4-46	141	24.8	4-46	100			16	T	
420	do	733.19	7-26	107	45.18	9-30	1,000	23	T	18	Ind	
421	Univ. of Dayton	1800		16	12.8	7-8-55			None	10	S	Dug. No longer used.

## Meraine district

601	Air Reduction Sales Co.	720	10-51	120	40.66	2-18-53	400		T	12	Ind	
602	Gene W. Baker	712	10-54	82	19	10-10-54	20	3	T	6	T	
603	Webster Baker	728	10-55	80	40	1-55			T	6	D	
604	Eugene Rots	826	12-54	220	138	12-20-54	20	10	T	6	D	
605	Calvary Cemetery	790	1918	120	108	8-20-57				4	Lrr	Dug to 70 ft, remainder drilled. 1' lost.
606	Carlton Culberts	840	1965	210	155	1965			R	6	R	

## PRIVATELY OWNED WELLS (Continued)

Well	Owner	Altitude (ft above sea level)	Diam drilled	Water level		Yield		Type of pump	Diameter of well (in.)	Use	Remarks
				Depth (ft)	Feet	Gpm	Draw-down (ft)				
Morrow district—Continued											
507	Carlisle Oakburn	750		10	10	0-10-30	1	Electric	2		
508	Central Realty Mfg Co	750	4-6	10	10	0-10-30	1	Electric	2		
509	City of Dayton, Miami View Golf Course	750	4-6	10	10	0-10-30	1	Electric	2		
510	do.	750	4-6	10	10	0-10-30	1	Electric	2		Not used.
511	A. R. Campbell	750	4-6	10	10	0-10-30	1	Electric	2		Driven.
512	Farmer Center	750	4-6	10	10	0-10-30	1	Electric	2		
513	Myron Campbell Co	750	4-6	10	10	0-10-30	1	Electric	2		
514	James Campbell Co	750	4-6	10	10	0-10-30	1	Electric	2		
515	Crane Brick Co	750	4-6	10	10	0-10-30	1	Electric	2		
516	H. G. Darrah	750	4-6	10	10	0-10-30	1	Electric	2		Stuck.
517	do.	750	4-6	10	10	0-10-30	1	Electric	2		11 1/2 in. pipe driven. Holed.
518	Dayton Power & Light Co., Service Hole	740	4-6	10	10	1-17-30	1	Electric	2		Drilled for use during construction.
519	do.	740	4-6	10	10	1-20-30	1	Electric	2		
520	Dayton Power & Light Co., Morrow Substa	730	4-6	10	10	1-21-30	1	Electric	2		
521	Dayton Power & Light Co., Frank M. Tait Co.	730	4-6	10	10	0-10-30	1	Electric	2		
522	do.	730	4-6	10	10	0-10-30	1	Electric	2		
523	do.	730	4-6	10	10	0-10-30	1	Electric	2		
524	do.	730	4-6	10	10	0-10-30	1	Electric	2		
525	do.	730	4-6	10	10	0-10-30	1	Electric	2		
526	do.	730	4-6	10	10	0-10-30	1	Electric	2		
527	do.	730	4-6	10	10	0-10-30	1	Electric	2		
528	do.	730	4-6	10	10	0-10-30	1	Electric	2		
529	do.	730	4-6	10	10	0-10-30	1	Electric	2		
530	do.	730	4-6	10	10	0-10-30	1	Electric	2		
531	do.	730	4-6	10	10	0-10-30	1	Electric	2		
532	do.	730	4-6	10	10	0-10-30	1	Electric	2		
533	do.	730	4-6	10	10	0-10-30	1	Electric	2		
534	do.	730	4-6	10	10	0-10-30	1	Electric	2		
535	do.	730	4-6	10	10	0-10-30	1	Electric	2		
536	do.	730	4-6	10	10	0-10-30	1	Electric	2		
537	do.	730	4-6	10	10	0-10-30	1	Electric	2		
538	do.	730	4-6	10	10	0-10-30	1	Electric	2		
539	do.	730	4-6	10	10	0-10-30	1	Electric	2		
540	do.	730	4-6	10	10	0-10-30	1	Electric	2		
541	do.	730	4-6	10	10	0-10-30	1	Electric	2		
542	do.	730	4-6	10	10	0-10-30	1	Electric	2		
543	do.	730	4-6	10	10	0-10-30	1	Electric	2		
544	do.	730	4-6	10	10	0-10-30	1	Electric	2		
545	do.	730	4-6	10	10	0-10-30	1	Electric	2		
546	do.	730	4-6	10	10	0-10-30	1	Electric	2		
547	do.	730	4-6	10	10	0-10-30	1	Electric	2		
548	do.	730	4-6	10	10	0-10-30	1	Electric	2		
549	do.	730	4-6	10	10	0-10-30	1	Electric	2		
550	do.	730	4-6	10	10	0-10-30	1	Electric	2		
551	do.	730	4-6	10	10	0-10-30	1	Electric	2		
552	do.	730	4-6	10	10	0-10-30	1	Electric	2		
553	do.	730	4-6	10	10	0-10-30	1	Electric	2		
554	do.	730	4-6	10	10	0-10-30	1	Electric	2		
555	do.	730	4-6	10	10	0-10-30	1	Electric	2		
556	do.	730	4-6	10	10	0-10-30	1	Electric	2		
557	do.	730	4-6	10	10	0-10-30	1	Electric	2		
558	do.	730	4-6	10	10	0-10-30	1	Electric	2		
559	do.	730	4-6	10	10	0-10-30	1	Electric	2		
560	do.	730	4-6	10	10	0-10-30	1	Electric	2		
561	do.	730	4-6	10	10	0-10-30	1	Electric	2		
562	do.	730	4-6	10	10	0-10-30	1	Electric	2		
563	do.	730	4-6	10	10	0-10-30	1	Electric	2		
564	do.	730	4-6	10	10	0-10-30	1	Electric	2		
565	do.	730	4-6	10	10	0-10-30	1	Electric	2		
566	do.	730	4-6	10	10	0-10-30	1	Electric	2		
567	do.	730	4-6	10	10	0-10-30	1	Electric	2		
568	do.	730	4-6	10	10	0-10-30	1	Electric	2		
569	do.	730	4-6	10	10	0-10-30	1	Electric	2		
570	do.	730	4-6	10	10	0-10-30	1	Electric	2		
571	do.	730	4-6	10	10	0-10-30	1	Electric	2		
572	do.	730	4-6	10	10	0-10-30	1	Electric	2		
573	do.	730	4-6	10	10	0-10-30	1	Electric	2		
574	do.	730	4-6	10	10	0-10-30	1	Electric	2		
575	do.	730	4-6	10	10	0-10-30	1	Electric	2		
576	do.	730	4-6	10	10	0-10-30	1	Electric	2		
577	do.	730	4-6	10	10	0-10-30	1	Electric	2		
578	do.	730	4-6	10	10	0-10-30	1	Electric	2		
579	do.	730	4-6	10	10	0-10-30	1	Electric	2		
580	do.	730	4-6	10	10	0-10-30	1	Electric	2		
581	do.	730	4-6	10	10	0-10-30	1	Electric	2		
582	do.	730	4-6	10	10	0-10-30	1	Electric	2		
583	do.	730	4-6	10	10	0-10-30	1	Electric	2		
584	do.	730	4-6	10	10	0-10-30	1	Electric	2		
585	do.	730	4-6	10	10	0-10-30	1	Electric	2		
586	do.	730	4-6	10	10	0-10-30	1	Electric	2		
587	do.	730	4-6	10	10	0-10-30	1	Electric	2		
588	do.	730	4-6	10	10	0-10-30	1	Electric	2		
589	do.	730	4-6	10	10	0-10-30	1	Electric	2		
590	do.	730	4-6	10	10	0-10-30	1	Electric	2		
591	do.	730	4-6	10	10	0-10-30	1	Electric	2		
592	do.	730	4-6	10	10	0-10-30	1	Electric	2		
593	do.	730	4-6	10	10	0-10-30	1	Electric	2		
594	do.	730	4-6	10	10	0-10-30	1	Electric	2		
595	do.	730	4-6	10	10	0-10-30	1	Electric	2		
596	do.	730	4-6	10	10	0-10-30	1	Electric	2		
597	do.	730	4-6	10	10	0-10-30	1	Electric	2		
598	do.	730	4-6	10	10	0-10-30	1	Electric	2		
599	do.	730	4-6	10	10	0-10-30	1	Electric	2		
600	do.	730	4-6	10	10	0-10-30	1	Electric	2		

838	do	728.4	7-46	122	32	7-10-81	1,200	7	T	20	Ind
839	do	728.7	7-46	122	37.8	7-10-81	1,000	20	T	20	Ind
840	do	728.8	7-46	122	36	8-12-80	1,000	7.25	T	20	Ind
841	do	731.6	11-48	111	37	11-12-80	1,000	10	T	20	Ind
842	do	734	10-80	108	32	10-27-80	1,200	5	T	20	Ind
843	do	728.79	1-84	112	47.75	8-17-84	800		T	6	Ind
844	do	728.87	1-84	112	47	9-9-84	900		T	14	Ind
845	do	728.95	12-47	128	40	12-47	1,000		T	14	Ind
846	do	730.77	4-81	174	40	8-22-82	1,700	19.5	T	20	Ind
847	do	731.08	4-81	122	34	9-6-81	1,200	8	T	20	Ind
848	do	734.02	4-81	116	30	4-17-81	1,700	10	T	20	Ind
849	do	734.02	1981	120					T		
850	do	741.37	3-82	126	36	3-14-82	1,300	12	T	20	Ind
851	do	787.4	6-82	42	42	8-18-82	1,800	12	T	20	Ind
852	do	757.4	6-82	148	42	6-12-82			T	8	
853	do	728.79	7-85	128	37.93	12-18-87	1,800	8	T	20	Ind
854	do	729.8	9-82	120	35	6-12-82			T		
855	do	729.37	9-84	121	33	8-12-84	1,000	15	T	20	Ind
856	do	729.37	9-85	125	42	8-17-85	1,200	10	T	18	Ind
857	do	729.37	7-86	265					T		
858	do	729	12-86	122	48	12-22-86	1,200	15	T	16	Ind
859	do	725	12-85	120					T		
860	do	729.79	10-85	115	36	10-10-86	1,000	10	T	18	Ind
861	do	727.79	10-85	199					T		
862	do	732.21	12-86	87	44.75	12-86	800		None	20	Ind
863	do	734.06		118					None	8	Ind
864	Clay F. Garrison	750	1984	80	80	3-27-87			None	4	Ind
865	Item Machine Co.	734	1-82	52	25	1-1-82	8.2	0	J	4	Ind
866	James Gray	734	10-86	80	29	10-18-86	2	80	J	10	Ind
867	Oil Refining Co.	823	9-86	134	117	9-26-86	30	0	J	4	Ind
868	Thierville Gutwain	784	1983	44	Flows	Full-85			None	4	Ind
869	Albert Hornby	740	48	82.63		6-28-88			Hand	4	Ind
870	Michael Hochmalt	723	9-84	76	38	9-10-84	15	2	J	0	Ind
871	(F. Lyle Holden	718	1984	45	31	8-20-87			J	0	Ind
872	Dallas Howell	710	12-85	44			30		J	0	Ind
873	Jackson Sand & Gravel Co.	745		65	41.75	4-10-85			J	0	Ind
874	George Johnson	720	8-84	45	28	8-10-84			J	0	Ind
875	Miss Kling	885	5-86	267	177	5-28-86	10	30	J	0	Ind
876	Kocelens Service Sta.	780	11-85	80	80	11-18-85	6		J	0	Ind
877	Morris Matuseff	780	11-84	85	42				J	0	Ind
878	Mrs. Edward McGinnis	815	1981	180	180	1981	75	0	J	0	Ind
879	Miami Shores School	720	12-88	100	30	12-10-88	125	0	T	10	Ind
880	Moraine Fox Co.	744	1927	60					T	8	Ind
881	Moraine Country Club	818	1987	125	125.5	2-20-87			T	8	Ind
882	National Cash Register Co. Roll Course	793.87	1982	74	85	4-20-83	32		None	10	Ind
883	do	787	1982	74	41.5	Spring-82	400	1.4	None	10	Ind
884	do	720.75	8-84	111	28	8-22-84	240		T	10	Ind
885	do	728.82	9-84	118	30	9-20-84	340		T	10	Ind
886	Hed Home Tourist Court	730	8-84	100	26-48	8-21-82			J	6	Ind
887	Brutley Rice	718	8-84	88	35				J	5	Ind
888	Delbert Roberts	720	1-84	44	18	1-18-84			J	5	Ind

Do.

Observation well.

Abandoned.

Do.

No.

PRIVATELY OWNED WELLS—Continued

Well	Owner	Alt. Feet (to nearest sea level)	Date drilled	Depth (ft)	Water level		Yield		Type of pump	Trans- mission loss (ft.)	Use	Remarks
					Depth (ft)	Date	Rate (gpm)	Pressure (psi)				
800	A. M. Shively	680	7-04	104	100	7-20-04	20	10	Hand	0	Ind	
801	Hubbard Co.	720	8-04	11	91	7-20-04	17	4	Hand	10	Ind	
802	do	720	8-04	94	81	7-20-04	17	4	Hand	10	Ind	
803	Harold H. Singer	720	8-04	84	80	7-11-04	17	4	Hand	10	Ind	
804	M. O. Snyder & Son Co.	820	1904	100	100	1904	17	4	Hand	10	Ind	
805	do	810	1907	100	100	1907	17	4	Hand	10	Ind	
806	do	810	1904	100	110	1904	17	4	Hand	10	Ind	
807	South Dayton Motel	720	1904	70	60	1904	17	4	Hand	10	Ind	
808	Southern Lumber Co., Inc.	710	11-04	91	80	11-04	1,000	1,000	Hand	10	Ind	
809	Frank M. Link	840		170	167	11-04	1,000	1,000	Hand	10	Ind	
810	do	840		200	184	11-04	1,000	1,000	Hand	10	Ind	
811	Paul Watson	720	8-04	80	60	8-04	1,000	1,000	Hand	10	Ind	
812	W. H. Wood	720	8-04	80	60	8-04	1,000	1,000	Hand	10	Ind	
813	John Ranch	720	8-04	80	60	8-04	1,000	1,000	Hand	10	Ind	
814	Frank Smith	720	8-04	80	60	8-04	1,000	1,000	Hand	10	Ind	
815	James J. Jones	820	1904	80	70	1904	1,000	1,000	Hand	10	Ind	
816	Dayton Brick Co.	720	1904	80	70	1904	1,000	1,000	Hand	10	Ind	
817	Dayton Community Golf Course	840		170	160	11-04	1,000	1,000	Hand	10	Ind	
818	Dayton Power & Light Co., Frank M.	720		80	70	11-04	1,000	1,000	Hand	10	Ind	
819	Tall Sta.	720		80	70	11-04	1,000	1,000	Hand	10	Ind	
820	Unknown	720		80	70	11-04	1,000	1,000	Hand	10	Ind	

MUNICIPAL SUPPLY WELLS

City of Dayton	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	
do	720	11-04	100	100	11-04	1,000	1,000	11-04	1,000	1,000	Ind	

40-ft screen.

## RECORDS OF WELLS IN THE DAYTON AREA

[illegible]

**FOURTH SUPPLY WHEELS continued**

Well	Owner	Alt. (ft. above sea level)	Date drilled	Depth (ft.)	Water level		Yield		Type pump	Diameter of well (in.)	Use	Remarks
					Depth (ft.)	Date	Rate (gpm)	Draw-down (ft.)				
T-1	City of Dayton, Miami River well	745	12-25	300					None	20	T	Observation well MT-22
		746	12-25	300	11.5	2-25-57	2,500	0	None			
		747	12-25	300					None			
		748	12-25	300					None			
		749	12-25	300					None			
		750	12-25	300					None			
		751	12-25	300					None			
		752	12-25	300					None			
		753	12-25	300					None			
		754	12-25	300					None			
		755	12-25	300					None			
		756	12-25	300					None			
		757	12-25	300					None			
		758	12-25	300					None			
		759	12-25	300					None			
		760	12-25	300					None			
		761	12-25	300					None			
		762	12-25	300					None			
		763	12-25	300					None			
		764	12-25	300					None			
		765	12-25	300					None			
		766	12-25	300					None			
		767	12-25	300					None			
		768	12-25	300					None			
		769	12-25	300					None			
		770	12-25	300					None			
		771	12-25	300					None			
		772	12-25	300					None			
		773	12-25	300					None			
		774	12-25	300					None			
		775	12-25	300					None			
		776	12-25	300					None			
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		778	12-25	300					None			
		779	12-25	300					None			
		780	12-25	300					None			
		781	12-25	300					None			
		782	12-25	300					None			
		783	12-25	300					None			
		784	12-25	300					None			
		785	12-25	300					None			
		786	12-25	300					None			
		787	12-25	300					None			
		788	12-25	300					None			
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		790	12-25	300					None			
		791	12-25	300					None			
		792	12-25	300					None			
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		796	12-25	300					None			
		797	12-25	300					None			
		798	12-25	300					None			
		799	12-25	300					None			
		800	12-25	300					None			
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		809	12-25	300					None			
		810	12-25	300					None			
		811	12-25	300					None			
		812	12-25	300					None			
		813	12-25	300					None			
		814	12-25	300					None			
		815	12-25	300					None			
		816	12-25	300					None			
		817	12-25	300					None			
		818	12-25	300					None			
		819	12-25	300					None			
		820	12-25	300					None			
		821	12-25	300					None			
		822	12-25	300					None			
		823	12-25	300					None			
		824	12-25	300					None			
		825	12-25	300					None			
		826	12-25	300					None			
		827	12-25	300					None			
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		831	12-25	300					None			
		832	12-25	300					None			
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		834	12-25	300					None			
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		838	12-25	300					None			
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		840	12-25	300					None			
		841	12-25	300					None			
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		846	12-25	300					None			
		847	12-25	300					None			
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		850	12-25	300					None			
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		903	12-25	300					None			
		904	12-25	300					None			
		905	12-25	300					None			
		906	12-25	300					None			
		907	12-25	300					None			
		908	12-25	300					None			
		909	12-25	300					None			
		910	12-25	300					None			
		911	12-25	300					None			
		912	12-25	300					None			
		913	12-25	300					None			

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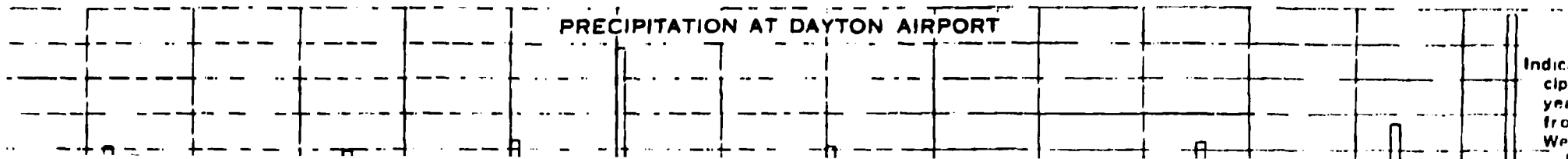
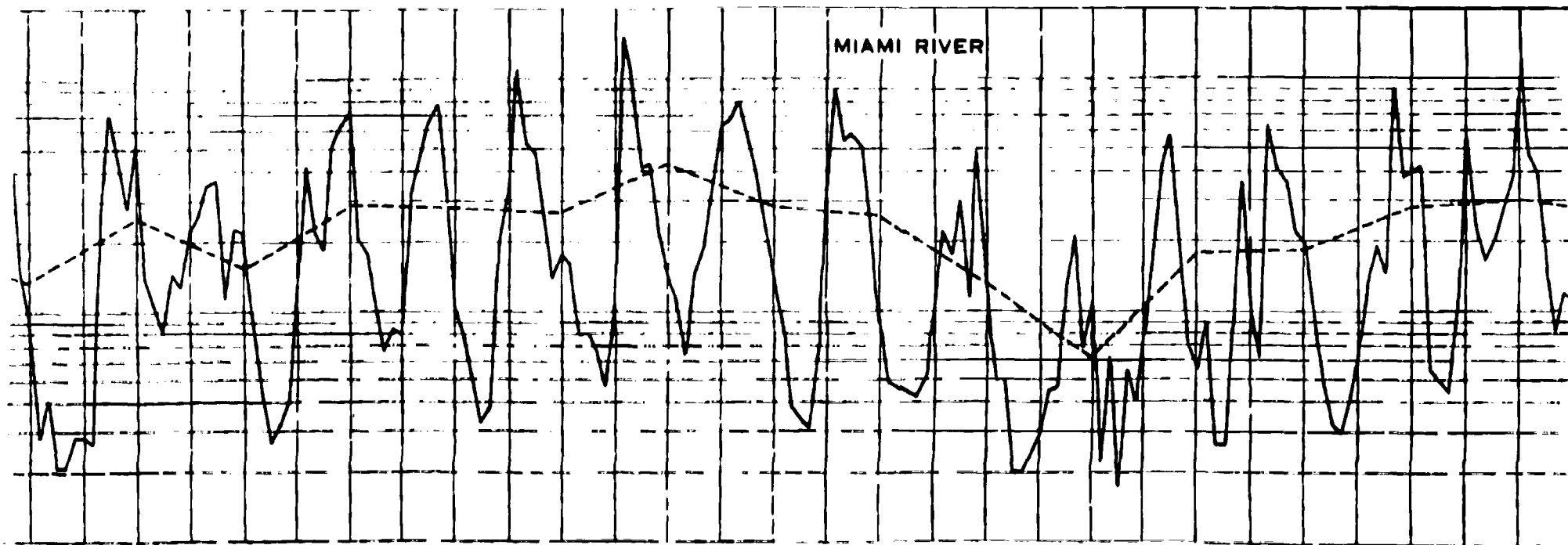
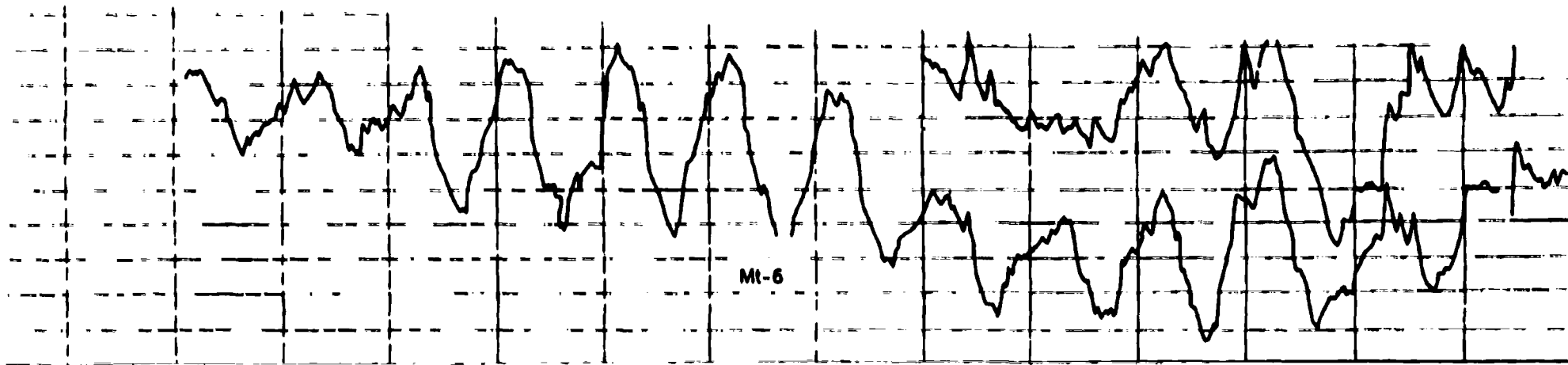
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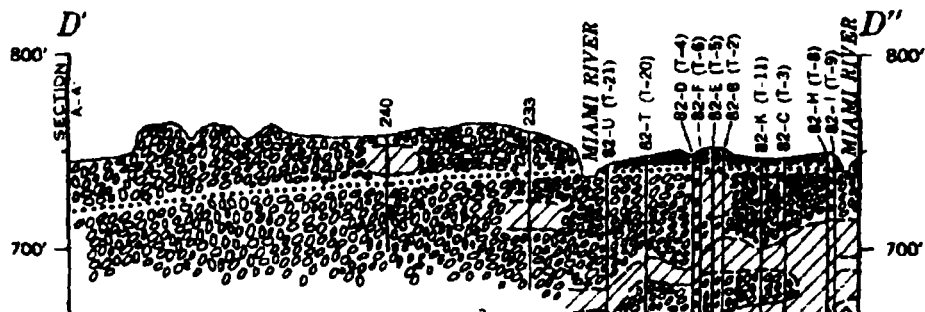
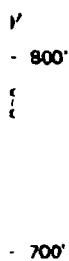
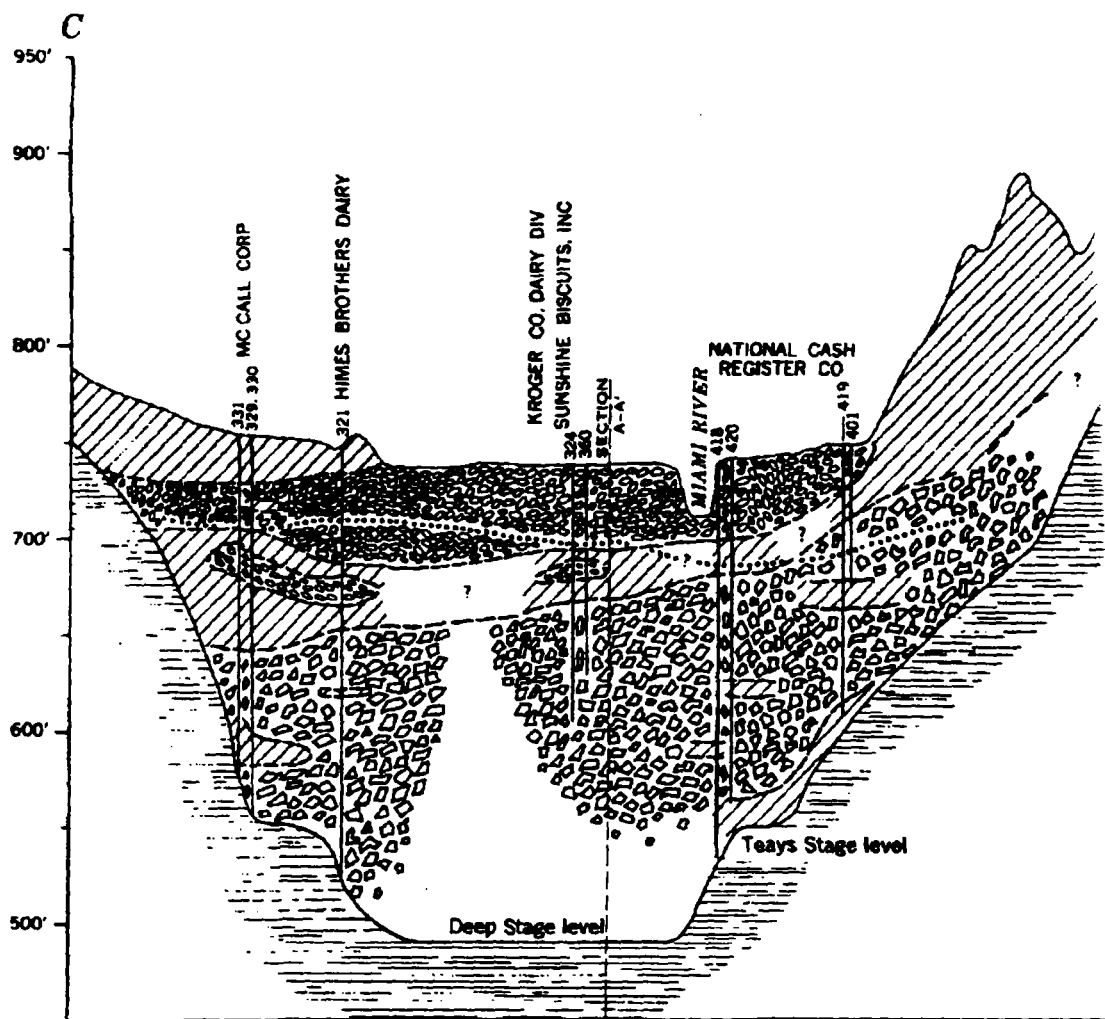
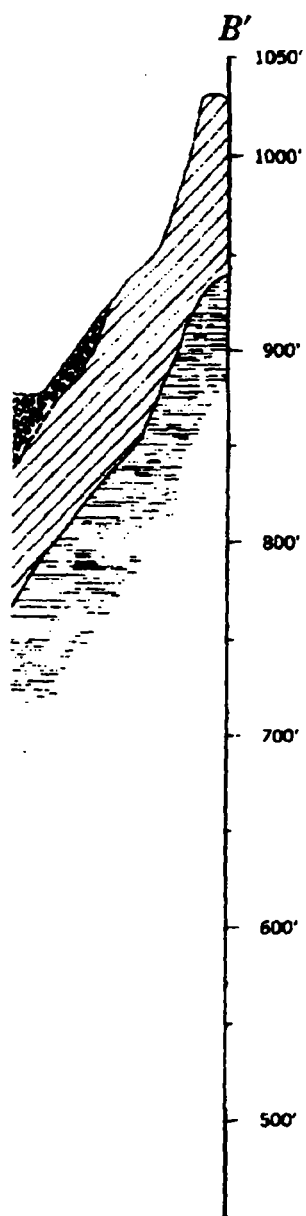
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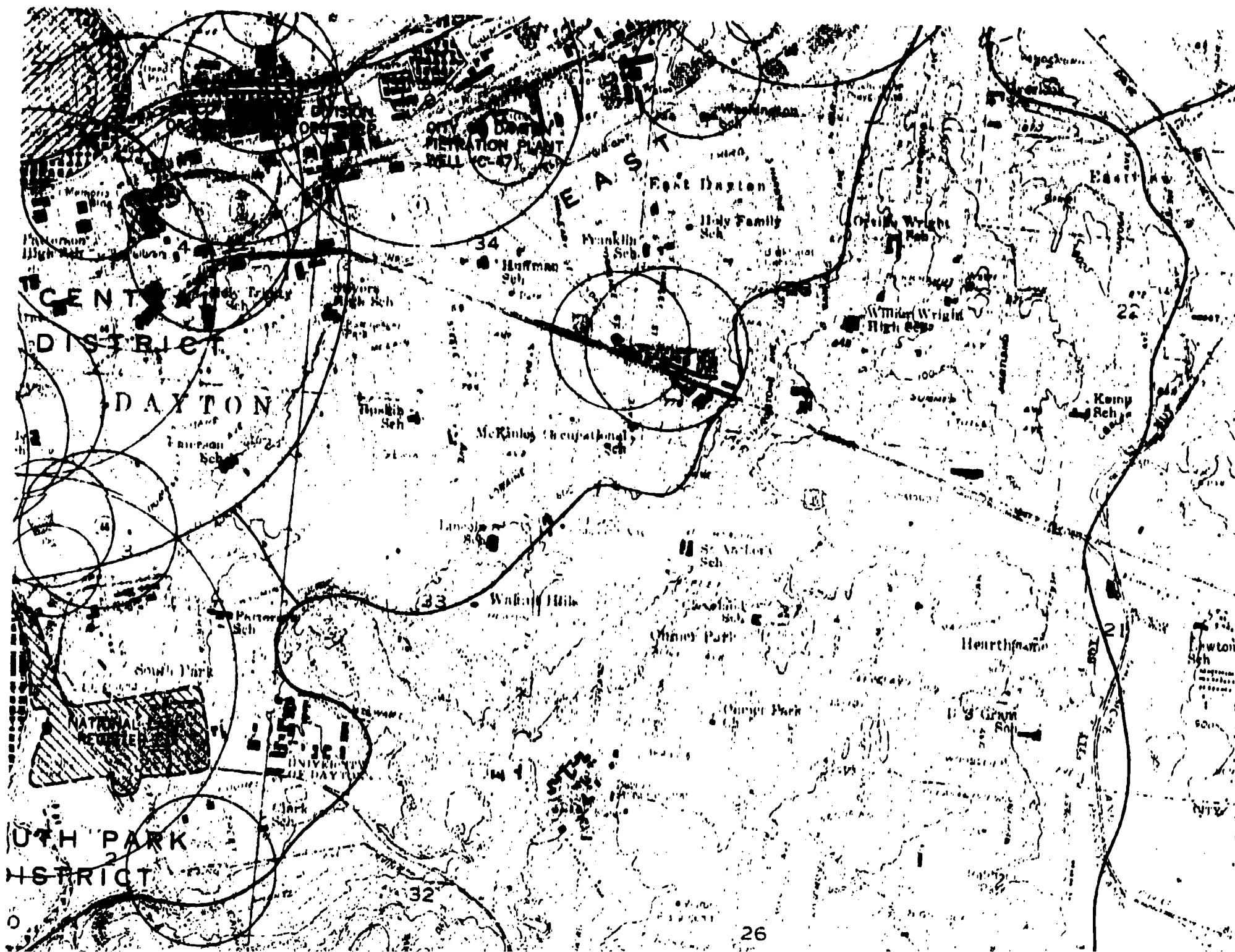
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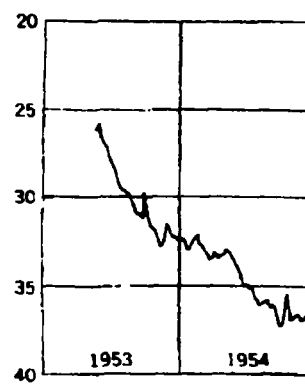
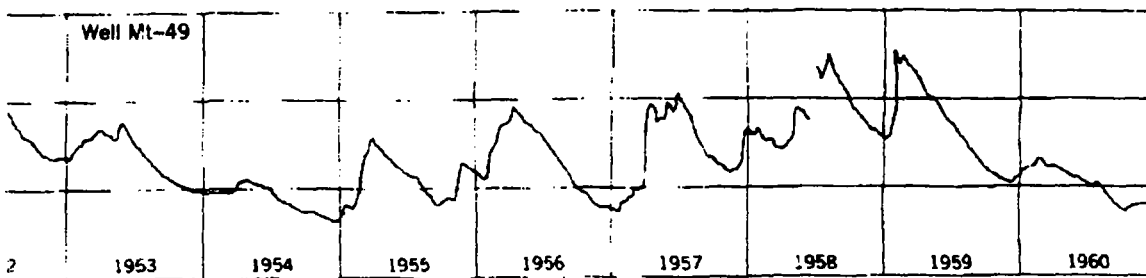
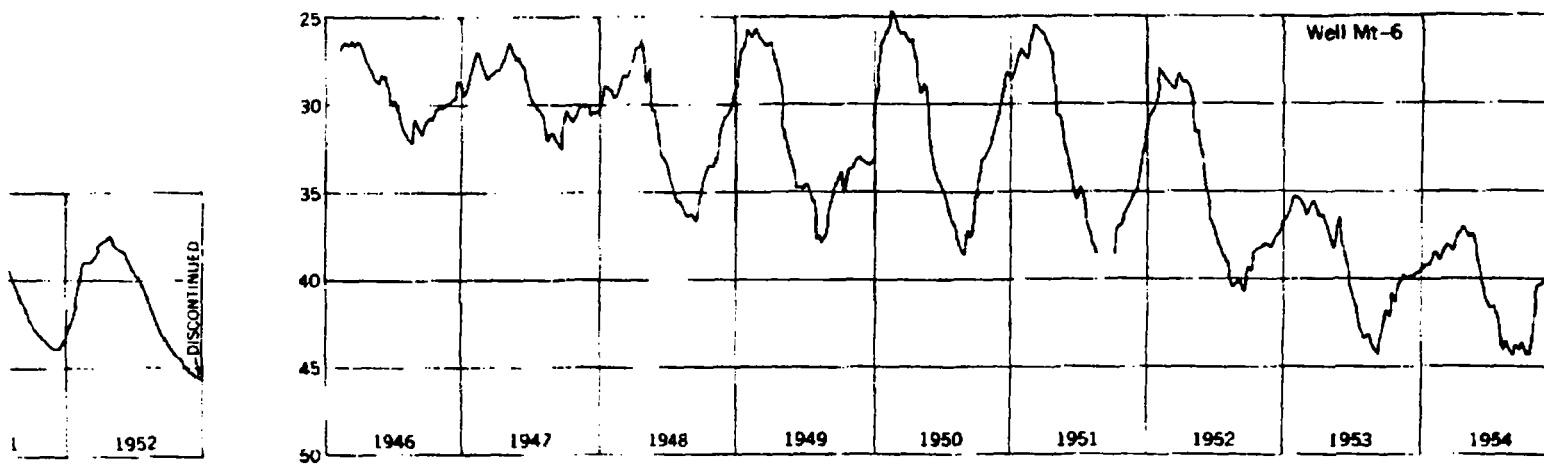
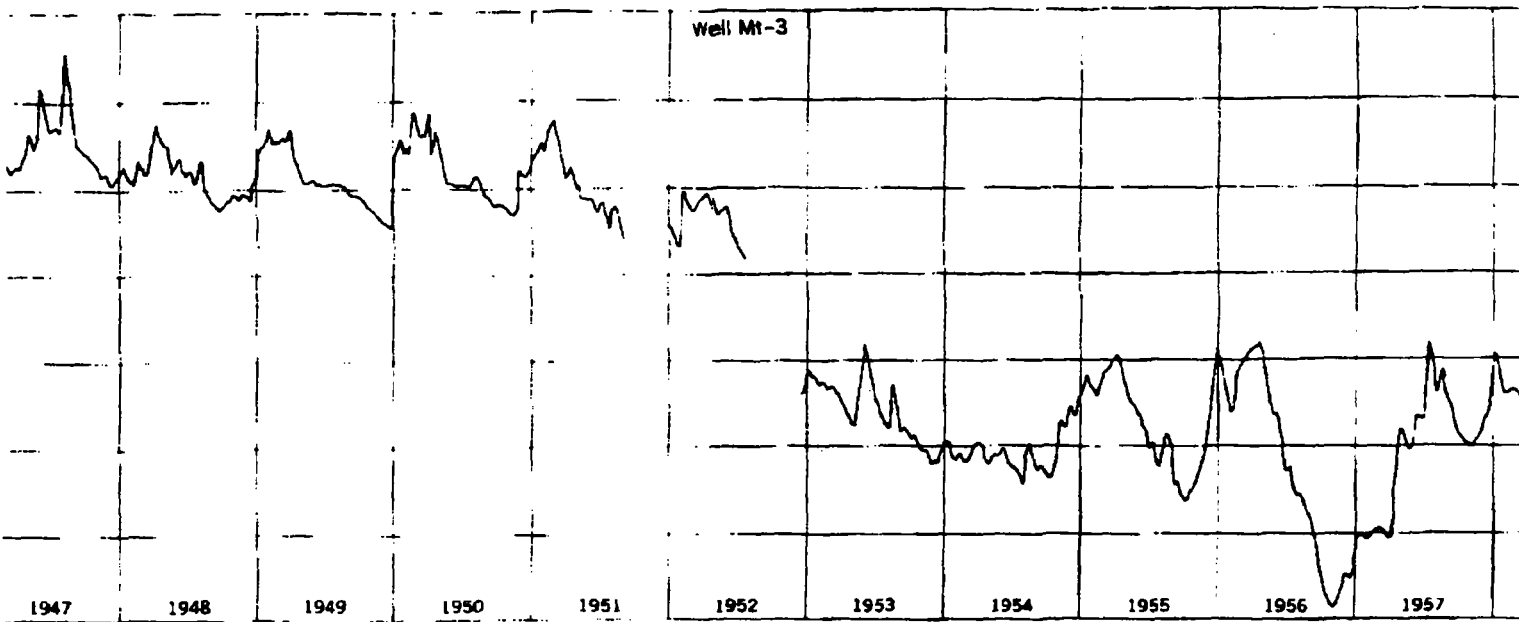
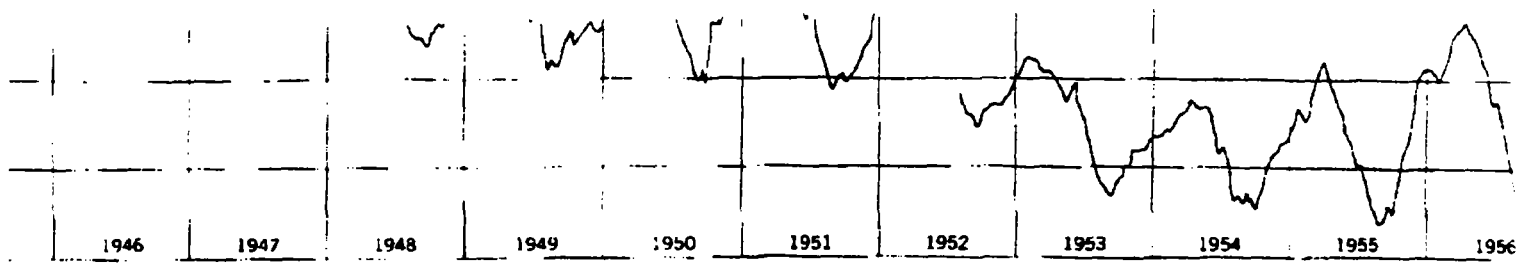


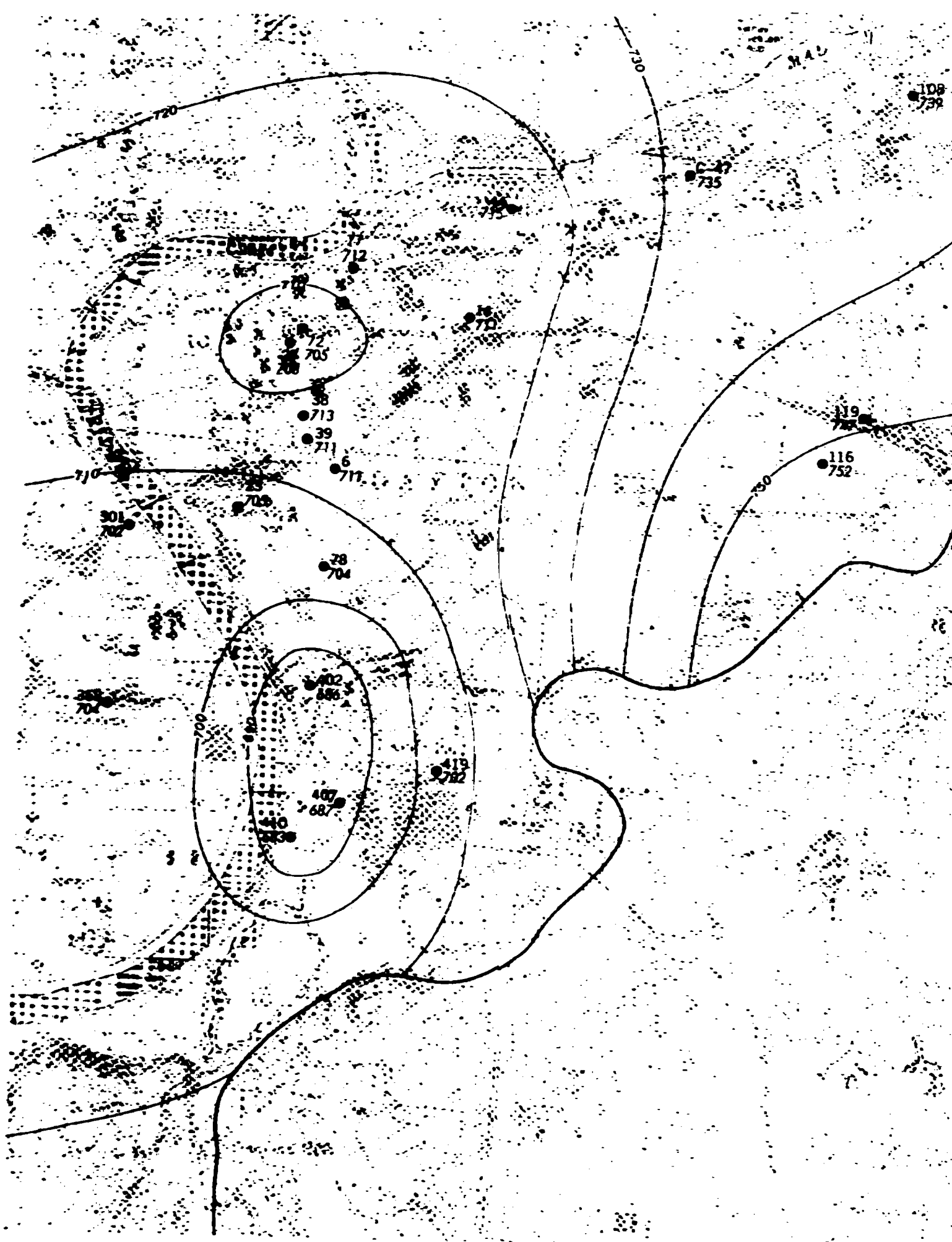


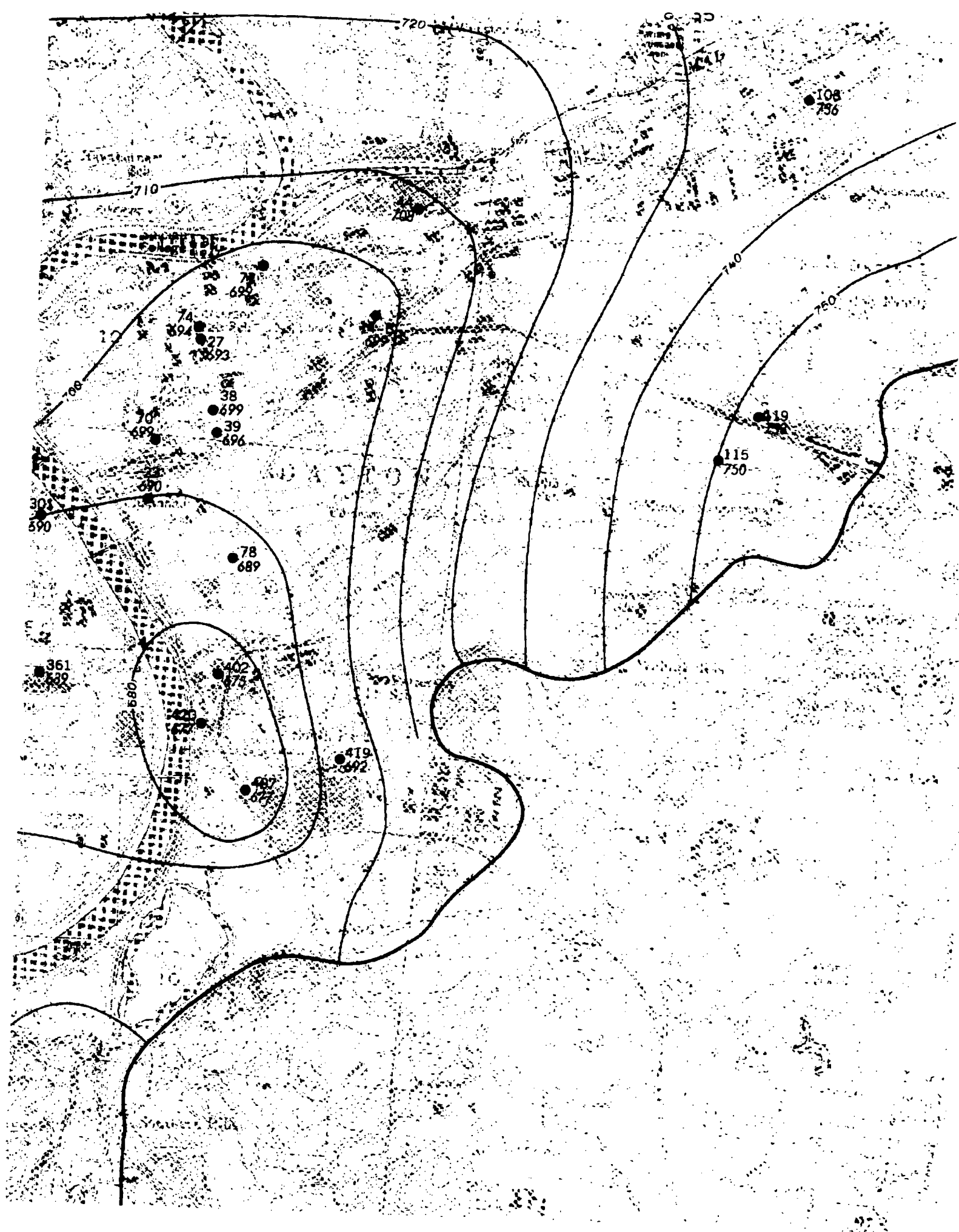












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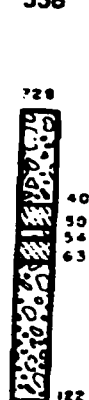
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